SLATE

IN

NORTHAMPTON COUNTY PENNSYLVANIA

CHARLES H. BEHRE, JR.

PENNSYLVANIA
GEOLOGICAL SURVEY
FOURTH SERIES
BULLETIN M 9

SLATE
IN
NORTHAMPTON COUNTY
PENNSYLVANIA

By

Charles H. Behre, Jr.

DEPARTMENT OF FORESTS AND WATERS
CHARLES E. DORWORTH, Secretary
TOPOGRAPHIC AND GEOLOGIC SURVEY
G. H. ASHLEY, State Geologist
HARRISBURG, PA.

1927

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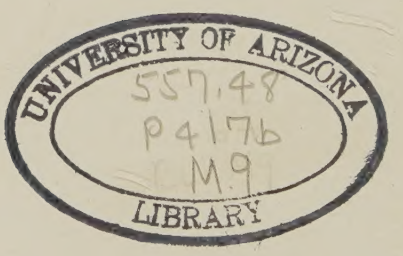
THE TELEGRAPH PRESS
Harrisburg, Pa.
1926



LETTER OF TRANSMITTAL

R. Y. Stuart, Secretary,

Department of Forests and Waters.

Sir:

I have the honor to transmit herewith the manuscript, maps, and illustrations for a detailed report on a part of the slate belt of Pennsylvania, by Charles H. Behre, Jr. As you doubtless know, Pennsylvania is the leading slate-producing State of the Union. The value of the slate produced annually in Pennsylvania is nearly one-half the value of all the slate produced in the United States. In 1923 and 1924 sales of Pennsylvania slate exceeded $5,000,000.00 a year.

The present report covers a portion of the slate belt of Lehigh and Northampton counties east of the Lehigh River. It is a minute study of those factors that determine the workability and value of the slate. No such careful study has ever before been made, and it should therefore be of large value to the men in the industry. Both the major and minor structural features of the slate belt have been worked out and shown on maps and sections. The general section of the slate rocks has been determined and measured, and the geologic history of the rocks outlined. The illustrations will be a revelation to many of our citizens as to the size and scope of the industry, the size and depth of the quarries, the processes of quarrying and preparing the slate, and the great volume of waste slate for which a use is being sought.

Respectfully,

Geo. H. Ashley

State Geologist.

January 20, 1926.

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SLATE IN NORTHAMPTON COUNTY, PENNSYLVANIA

By Charles H. Behre, Jr.

INTRODUCTION

FIELD AND OFFICE WORK

The field work represented by this report was carried on under the auspices of the Pennsylvania Topographic and Geologic Survey during the summers of 1923 and 1924. The first summer was spent wholly in the field. Quarry locations were made on the maps by plane table methods, using photographic enlargements of topographic maps for a base. In the second summer much time was spent indoors organizing the data assembled. Sporadically field trips were also made during the fall and winter of 1923 and the spring of 1924.

The office work was finished in June 1925.

SOURCES OF INFORMATION

Two general sources of information, other than that obtained by personal observation, were available in the preparation of this publication,—the reports of earlier geologists and the statements of quarrymen. For the geology of slate in general, the excellent work of Dr. T. Nelson Dale of the United States Geological Survey became the foundation upon which these studies could be built. The general stratigraphy and structure of this and adjacent regions have been described in more or less detail by the geologists of the United States, Pennsylvania, New Jersey, and Maryland Geological Surveys. Dr. Oliver Bowles of the United States Bureau of Mines has given much valuable information on the technology of slate in interviews and in his writings. Production data were obtained from the Mineral Resources Division of the United States Geological Survey.

For information as to the development of individual slate quarries, some of the pioneers in the slate district were consulted. In many quarries which are now abandoned, details of structure and stratigraphy could not be studied and data could be gleaned only from the men who were once engaged in quarrying in these particular openings; here again, therefore, quarrymen were called upon and responded generously. In the use of such data the writer has sought to discriminate between statements that appear to be in accord with observed facts and those which, because of the filling of the openings or similar causes, could not be tested and have to be accepted, if at all, "on faith."

ACKNOWLEDGMENTS

To acknowledge all assistance received in preparing this report would be to fill several pages. Especial thanks are due to Dr. B. L. Miller for repeated and valuable suggestions; to Mr. R. W. Stone, of the Pennsylvania Topographic and Geologic Survey, for his careful editing of this publication; to Mr. Homer H. Kirby, of the Interstate Commerce Commission, for his contribution on the valuation of slate lands; to Mr. Malcolm K. Buckley, for analyses of several slate samples; to Dr. Geo. P. Merrill of the U. S. National Museum, for the loan of some forty thin sections of American slates; to Dr. Edson S. Bastin for careful reading and helpful criticism of the report; to my associates Dr. W. H. Bucher, and Mr. O. C. von Schlichten, for suggestions in regard to the structure and petrography of the slate; and to the Bliss Studio, Easton, for several photographs. The writer is also especially indebted to Dr. T. Nelson Dale, formerly of the U. S. Geological Survey, for the inspiration furnished by his excellent pioneer work on the economic geology of slate.

The heartiest cooperation and most kindly assistance was given by the slate operators. To acknowledge full indebtedness is impossible, but mention should be made of the aid furnished by Messrs. W. L. Blake, Wm. H. Smith, and M. J. Spry of Bangor, and Mr. Wm. Bray of East Bangor, recently deceased. The officials of the Structural Slate Company, Mr. Richard Jackson, 3d, of Pen Argyl and Mr. Wm. Smith of Chapman were courteous in furnishing all information requested. To these and the other operators who so generously gave of time and energy the writer wishes to extend his warmest thanks.

My wife, Dr. J. A. Behre, assisted me in much of the field work by her skillful use of the telescope alidade and plane table, and was my constant inspiration in preparing the illustrations and writing this report.

GEOGRAPHY

LOCATION OF THE DISTRICT

Boundaries.—The region here described includes portions of the Delaware Water Gap, Wind Gap, and Allentown quadrangles (See Fig. 1). As the purpose of the field work was primarily the preparation of a report on the slate in these three quadrangles, studies were not carried beyond the crest of Blue Mountain to the north, nor south of a line drawn through the towns of Belvidere in New Jersey and Nazareth and Bath in Pennsylvania. The western edge of the Wind Gap quadrangle, approximately 1½ miles east of Danielsville, and passing through Slatefield, is the western limit of the section mapped.

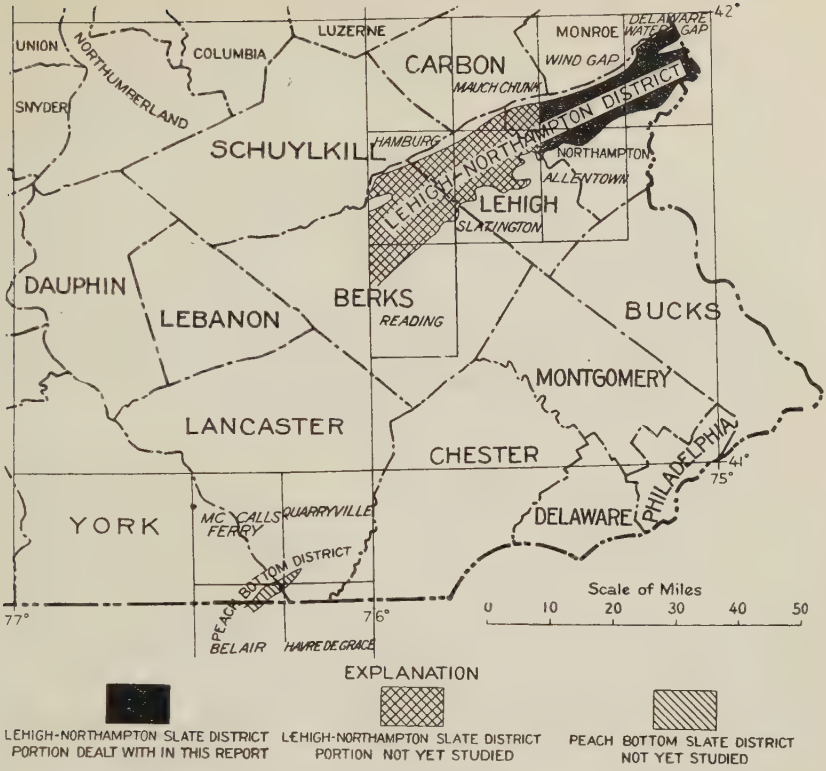

Figure 1. Outline map of Pennsylvania, showing the two important slate belts of the State, with the counties and quadrangles in which they occur.

The eastern edge coincides with the boundary between Pennsylvania and New Jersey, namely, Delaware River.

The section thus delimited has its extreme northern and southern limits at 41°57′30″ and 40°41′00″ north latitude respectively, and its eastern and western ones at 75°03′00″ and 75°30′00″ west longitude respectively. It includes approximately 195 square miles.

Cities and towns.—The area studied is about 60 miles due west of New York City and the same distance directly north of Philadelphia. It is thus distinctly tributary, in a commercial sense, to these two cities. Within the region, there are several smaller towns, formerly slate centers but now largely dependent on textile mills; notable are Bangor, Pen Argyl, and Wind Gap. Along the southern border of the district are situated Belvidere, Nazareth, and Bath, but in these the quarrying and preparing of limestone for Portland cement far overshadows the slate trade. Several smaller settlements, chiefly trading centers for the surrounding farms, are scattered throughout the area. Portland and Slateford are on the eastern border of the mapped area and on the west bank of Delaware River; Slateford was once a slate-making center,

but its quarries are now abandoned. At present, Bangor and Pen Argyl are the main centers of the slate industry in the area.

Transportation facilities.—The district is accessible over several railroads. A branch of the Lehigh and New England leads north from Bethlehem through Bath and the town of Chapman, where large slate quarries are located. It meets the Saylorsburg division of the same railroad at Benders Junction, whither the latter runs from Slatington; the railroad tracks continue along the southern escarpment of Blue Mountain to the Wind Gap; here a track passes through the mountain going northward to Saylorsburg while another continues eastward to Pen Argyl. Pen Argyl is connected with Nazareth by the Lehigh and New England Railroad and by a division of the Delaware, Lackawanna and Western Railway. The Lehigh and New England Railroad furnishes connections between Pen Argyl and Portland via Bangor. Along Delaware River the Pennsylvania and the Delaware, Lackawanna, and Western railroads lead southward and southeastward respectively from Delaware Water Gap. It is seen that railway connections are ample for freight shipments. Electric cars connect Bethlehem and other cities with Nazareth. A separate electric line runs from Nazareth to Bath. The Northampton Transit Company operates cars from Nazareth to Bangor*; the Slate Belt Electric line does likewise, but over a slightly different route, through Wind Gap and Pen Argyl. Electric cars also operate between Bangor and Portland, where they are met by cars which make the trip to Stroudsburg through the Delaware Water Gap.

PHYSIOGRAPHIC FEATURES OF THE DISTRICT

This part of southeastern Pennsylvania falls recognizably into three physiographic regions, the boundaries of which are roughly parallel and follow a northeast by north trend. In order from southeast to northwest, these are the limestone valley, the slate terrace, and Blue Mountain.

Limestone valley.—Along the southern part of the area here described is a continuous low-lying section that rises to altitudes between 300 and 400 feet above mean sea level. This region, which is mainly underlain by limestone, is characterized in a major way by its depressed surface in comparison with the areas to the south and north. In a minor way it is marked by sink-holes and pits, made by the collapse of the roofs of caverns; these are due to the solution of the limestone by underground water. Its stream valleys are wide and the streams meander as they cross the area.

Slate terrace.—The term Appalachian Valley is generally made to include both the limestone district, with its elevation of 400 feet or less, and the region hereinafter referred to as the slate terrace. Prop-

*Now replaced by automobile route.

erly, the writer believes, the moderately elevated slate country should be distinguished from the limestone valley to the south and Blue Mountain to the north, between which it forms a sort of terrace or

PLATE I

A. Escarpment between slate terrace and limestone valley (foreground.)

B. Blue Mountain (surmounted by the Kittatinny peneplain), with the slate terrace in the foreground.

C. Hilly topography typical of the middle, sandy member of the Martinsburg formation; west of Richmond.

step. (See Plate I, A-B) A narrower bench lies between this terrace and the valley, representing the outcrop of the slightly more readily eroded Jacksonburg limestone, to which reference will be made again further on. This bench can most easily be included in the limestone valley region.

The contrast between the stream valleys in this province and those in the limestone valley is striking. The Lehigh and Delaware Rivers have gently sloping banks in the limestone valley; where they cut through the slate terrace, however, the banks are steep and rugged and frequently well timbered. Tributary streams such as the Monocacy, meander across the limestone valley, but maintain straight courses between more precipitous bluffs as they flow through the terrace.

Blue Mountain.—Blue Mountain is the southernmost of a series of parallel ridges which, gradually becoming more and more confluent toward the northwest, finally lead toward the great escarpment of the Allegheny Plateau in northern and western Pennsylvania. As a physiographic unit, Blue Mountain is far more distinct from the slate terrace to the south than is the limestone valley. In this area it rises to altitudes of 1,660 feet above the sea and so lies well above any of the other physiographic regions described. It presents a southward flank that is almost perfectly aligned and continuous, but for a few wind gaps and the gorges cut by the Delaware and Lehigh rivers. Only the master streams have been able to cut through this prominent ridge; the minor streams generally appear as small rivulets, flowing out from under the talus of the south slope, or, unable to pass the barrier of hard rock that caps the ridge, content themselves with following courses that lead southwesterly or northeasterly to a union with the Lehigh or Delaware rivers. Blue Mountain is also known as Kittatinny Mountain.

General physiography.—In this larger setting, the area to be described takes the general form of a rectangle parallel to Blue Mountain, with its northwesterly edge on the crest of that eminence and its southeastern edge slightly south of the southern border of the slate terrace. A northwestward section across the surface would thus include, from south to north:

(a) The low northerly edge of the Appalachian Valley, with rather wide U-shaped river valleys and a general altitude of 400 feet; to the north this rises forty feet to form a bench.

(b) From this, a rapid rise to an elevation of 700 feet or so. From this escarpment a badly dissected and rather undulating table land extends northward to the foot of Blue Mountain.

(c) A slope rising from 700 feet to 1,500 feet above sea level,

generally beset with fine talus or large blocks derived from the erosion of Blue Mountain.

Minor features of this topography merit more detailed description under the section dealing with the geologic history of the region.

CLIMATE AND VEGETATION

The climate of the region is moderate and equable. The precipitation in recent years has been about 45.71 inches annually, ranging from 40.03 inches in 1914 to 55.66 in 1919.

Average precipitation at Stroudsburg, Pa., 1911-1921

	Inches		Inches
January 1911-1920	3.39	July 1911-1919	5.11
February 1911-1920	3.04	August 1911-1919, 1921	5.07
March 1911-1919, 1921	3.92	September 1911-1919, 1921	3.11
April 1911-1919, 1921	3.86	October 1911-1919, 1921	3.76
May 1911-1919, 1921	3.54	November 1911-1919, 1921	3.09
June 1911-1919, 1921	4.29	December 1911-1919, 1921	3.64

Average precipitation at Belvidere, N. J., 1914-1924

January 1914-16, 18-24	3.76	July 1915-1924	5.14
February 1914-16, 18-24	3.50	August 1915-1924	3.67
March 1915-1924	3.27	September 1915-1924	3.83
April 1915-1924	3.78	October 1915-1924	2.58
May 1915-1924	3.97	November 1915-1924	2.95
June 1915-1924	4.03	December 1915-1924	3.71

The region under discussion is between Belvidere and Stroudsburg.

The temperature seldom falls below 0° Fahrenheit in the winter, but is sufficiently cold to effectively stop quarrying in the deeper quarries during the winter months, and snow and ice are not uncommonly seen on north flanks of declivities or in shady ravines as late as the middle of April.

The area is fairly well settled and under extensive cultivation. In the limestone valley only small tracts of timber appear.

On the slate terrace deciduous trees of many varieties abound and the country is less densely settled so that small areas of forest growth are not lacking; in the sandy patches of the slate belt conifers—mainly pitch pine (*Pinus rigida, Mill*), Jersey pine (*P. virginiana,* Mill), red cedar, and hemlock are not uncommon, and some sections, such as the valley of Mud Run, between Stockertown and Martins Creek, are well wooded; deciduous trees are more common than ever-

greens. Along the flank of Blue Mountain the woods are thickest; conifers are rare here; the ground is in places heavily covered with *Selaginella;* rhododendron (*R. maximum, L.*) and various species of azalea are not uncommon, especially near the Delaware Water Gap. Virginia creeper (*Psedera quinquefolia, L., Greene*) and poison ivy (*Rhus radicans, L.*) are omnipresent. The crest of Blue Mountain is said once to have been well timbered, but today little remains save a close, scrubby growth of oaks five or six feet high, interspersed with thickets of lesser shrubs.

GENERAL GEOLOGY

SUMMARY

Although a single formation underlies by far the greater part of the region here described, (See Plate II, in pocket) the need of an understanding of the general sequence and structure justify a brief summary of all of the formations and of their structural relations in this part of Pennsylvania. The sequence is as follows:

Quaternary:	Recent alluvium
	Glacial deposits
Unconformity.	
Silurian (?):	Shawangunk conglomerate and sandstone
Unconformity.	
Ordovician:	Martinsburg formation (slate)
	Jacksonburg limestone (cement rock)
	Unconformity
	Beekmantown limestone
Cambrian:	Allentown limestone
	Probable unconformity
	Tomstown limestone
	Hardyston quartzite

South of the area here described there are, in addition, rocks of pre-Cambrian and of Triassic age, but the former are deeply buried beneath Paleozoic sediments and the latter apparently never extended as far north as the region here mapped. All of the rocks of the column listed above, with the exception of the Hardyston quartzite and possibly the Tomstown limestone are to be seen in the area described in this report. Generally the formations appear at the edges of the Martinsburg shales, where their occurrence is due either to the normal sequence or to faulting.

The general structure of these sediments is a monocline dipping northwest. In a northward route, the observer thus traverses a series

of rocks which are encountered in the order of their deposition. They are intensely folded, the axes of the folds extending both parallel and at right angles to the general axis of the Appalachian mountains, but the strike is more commonly northeasterly than otherwise and the dip, although variable, most commonly is to the northwest. This larger structure, which may be described as complexly monoclinal, is further confused by faulting, the faults being of two general types. Some of the fractures are parallel to the general strike of the folded structures and represent thrusts; others are inclined to the strike of the beds at marked angles, which are, however, by no means always as high as 90°, and produce minor offsets of the strata along their strike. As might be expected where the beds are as complexly folded as here, secondary cleavage and jointing are also well developed.

DETAILED STRATIGRAPHY

CAMBRIAN SYSTEM

Hardyston Quartzite

Description.—The beds immediately north of the pre-Cambrian rocks that form the hills at Bethlehem are quartzitic sandstone of Cambrian age. The name Chickies, or rather Chiques, was first proposed for this formation by Lesley in 1892.[1] In New Jersey, this has been called the Hardyston quartzite.[2] It is a massive sandstone, locally conglomeratic or slaty and generally arkosic (bearing feldspar). It is commonly pinite-bearing at the base, and as it contains grains of feldspar and pebbles of quartz, isolated exposures are distinguished with difficulty from the superficially similar acid gneisses of older age on which it rests. Although in places quartzitic, with a distinct secondary growth of quartz enveloping the original sand grains, it is elsewhere merely a porous sandstone with siliceous or even calcareous cement.

Generally this formation merely forms a portion of the slopes of the higher land underlain by older rocks.

The Hardyston quartzite lies everywhere unconformably upon the pre-Cambrian. In New Jersey its thickness has been estimated as not exceeding 200 feet, but changes within short distances along the strike.[3] In the Allentown quadrangle it ranges from 20 feet near Freemansburg to 300 feet near Emaus.[3]

Age and correlation.—Walcott[4] long ago reported the finding of *Scolithus linearis* and *Hyolithellus micans* in these beds near Reading and on this basis the strata were assigned to Cambrian age. Even

[1]Lesley, J. P., A summary description of the geology of Pennsylvania: Pa. Second Geol. Survey, vol. 1, p. 165, 1892.

[2]Lewis, J. V., and Kummel, H. B., The geology of New Jersey: New Jersey Dept. of Conservation and Development, Bull. 14, p. 44, 1915.

[3]Miller, B. L., Mineral resources of the Allentown quadrangle, Pennsylvania: Pennsylvania Top. & Geol. Survey, Atlas 206, p. 26, 1925.

[4]Walcott, C. D., Notes on the Cambrian rocks of Pennsylvania from the Susquehanna to the Delaware: Am. Jour. Sci., 3d ser., vol. 47, p. 39, 1894.

earlier the same conclusions were reached by Lesley.[5] More recently a species of *Olenellus* has been found in the sandstone,[6] which places it definitely in the Lower Cambrian.

No locality is known where this formation actually comes in contact with the Martinsburg slate. It is not seen at the surface in the areas mapped, but forms the basement on which the Cambrian and Cambro-Ordovician limestones next to be described were laid down.

Cambrian Limestones

Nomenclature.—The Cambrian limestones have been distinguished by Miller[7], and Peck[8], and others. They have been generally grouped together with the overlying more highly dolomitic limestones under the name Kittatinny limestone[9] and Shenandoah limestone[10], names which, although not strictly synonymous, nevertheless served conveniently to designate a thick series of dolomitic beds, generally poor in fossils and of related ages. More recent study by Stose, Miller, and others, however, has facilitated the subdivision of these beds as they occur in and near the area here studied into the following three formations, in descending order: Beekmantown limestone, Allentown limestone, Tomstown limestone.

Of these the lower two are of Cambrian age, the upper of Ordovician.

Topographic expression.—These limestones make the basement of the Appalachian Valley. The rounded yet distinct escarpment marking the northward extent of the Beekmantown and the two lower limestones rises two hundred feet or so above the general level of the valley and is very conspicuous in the field and on the map.

Tomstown Limestone

The Tomstown formation was given its name by Stose[11] who first separated it from the other members of the Shenandoah limestone near Waynesboro, Pennsylvania. In his report on limestones, Miller[12] applied the same name to the thousand or fifteen hundred feet of dolomitic limestone overlying the Hardyston quartzite. Peck[13], however, has preferred the name Leithsville formation.

The Tomstown limestone is a blue-gray, sandy, cherty, or clayey mag-

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[5]Lesley, J. P.: Op. cit., p. 165

[6]Lewis, J. W. and Kummel, H. B.: Op. cit., p. 45.

[7]Miller, B. L., personal communication.

[8]Peck, F. B., Preliminary report on the talc and serpentine of Northampton County, etc.: Top. and Geol. Survey of Pennsylvania, Report No. 5, p. 25, 1911.

[9]Weller, Stuart, The Paleozoic faunas: New Jersey Geol. Survey, Report on paleontology, vol. III. p. 11, 1903.

[10]Mathews, E. B., Correlation of Maryland and Pennsylvania Piedmont formations: Geol. Soc. Am., Bull., vol. 16, p. 340, 1905.

[11]Stose, G. W., U. S. Geol. Survey Geol. Atlas, Mercersburg-Chambersburg, folio, No. 170, p. 5, 1909.

[12]Miller, B. L., Limestones of Pennsylvania: Pennsylvania Top. & Geol. Survey, Bull. M. 7, p. 106, 1925.

[13]Peck, F. B.: Op. cit., p. 25.

nesian limestone. Its lower beds are said to contain a sandy phase grading downward into the Hardyston quartzite. Higher up the formation becomes more argillaceous, or, having been folded, shows thinner sericitic beds due to the alteration of clayey matter.

This limestone has an estimated thickness of a thousand feet, but folding and faulting complicate all measurements.

Near the type locality in south-central Pennsylvania, Stose reported the finding of a species of *Salterella*[14] and other localities from which *Kutorginia* and *Olenellus* have been collected. Insofar as the writer is aware, no fossils have been collected from the limestones in the neighborhood of the section here mapped. If it is true, as Miller maintains, that the lower thousand-odd feet of the limestone overlying the Hardyston are the equivalent of the Tomstown in the type locality, the age of the rock is clearly lower Cambrian.

Allentown Limestone

The Allentown limestone[15] has been so named from the type occurrence at Allentown, Pennsylvania. It is the thickest member of the Cambrian series in the region studied and by far the most commonly seen in the none too frequent outcrops. It consists of limestone, white, buff, or light slaty gray in color, in beds which vary in thickness from three inches to three feet. Chert and flint nodules are not lacking, but are rarer than in the Tomstown limestone; highly sericitized layers, also, are less generally observed. The formation contains much oolite and shows ripple-marks and cross-bedding, both of which suggest a shallow-water origin. A conspicuous feature is the presence of a species of *Cryptozoon,* probably *C. proliferum;* this forms large, disc-like bodies, averaging a foot in diameter, which are almost the only fossils to be found.

This formation has an estimated thickness of about 1500 feet.

In isolated localities in New Jersey small collections of fossils have been made which clearly indicate the upper Cambrian age of the Allentown limestone; in southeastern Pennsylvania only one form, a *Lingulella* resembling *L. acuminata,* is mentioned by Ulrich.[16]

It thus appears that there is a marked hiatus between the fossiliferous part of the Tomstown, at least in southeastern Pennsylvania, and the Allentown limestone. This hiatus apparently represents middle Cambrian time, during which, in south-central Pennsylvania, the Waynesboro and Elbrook formations or their equivalents were being laid down. A probable disconformity has therefore been sug-

[14]Stose, G. W.: Op. cit., p. 5.

[15]Wherry, E. T.: The early Paleozoic of the Lehigh valley district, Pennsylvania: Science, N. S., vol. XXX, p. 416, 1909.

[16]Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. Am., Bull., vol. XXII, p. 645, 1911.

gested by Ulrich, who states that during the middle Cambrian the area from the Harrisburg axis northward remained emerged.[17]

Although typical outcrops present clearly differing appearances, the Tomstown and Allentown limestones are distinguished with difficulty when seen in small exposures. Recognizable Allentown was seen at the edges of the section mapped, but some of the magnesian limestone may also have been of Tomstown age. As this report deals primarily with the slate, no attempt was made to separate the Tomstown and Allentown formations and they are mapped together, being indicated by the same symbol.

A large quarry of Cambrian limestone is opened in the Delaware Water Gap area about 500 feet south of the Portland postoffice and east of the Delaware River highway. It measures 300 by 200 feet and is 75 feet deep, so that a good section is exposed to view. Although no fossils were collected here, the general character of the beds supports a correlation with the typical Allentown limestone. The quarry face shows alternate beds of dark blue-gray magnesian limestone and light-gray dolomite. Both types of rock bear black flint nodules. Some of the rock is oolitic. Occasional shaly layers are present. In thickness the separate layers vary up to five feet, the average being 1½ feet.

Near the bottom of the quarry is a bed bearing a small form of *Crytozoon*, the separate "arches" formed by this organic structure being generally about one inch in diameter. Near the top of the quarry a very thick bed rich in a much larger *Cryptozoon* can be seen from below.

ORDOVICIAN SYSTEM

Beekmantown Limestone

Nomenclature.—A detailed study of the lithology and paleontology convinced Weller that the Kittatinny limestone of New Jersey displayed here and there, below its irregularly eroded upper boundary, a distinct facies, not to be lumped with the Allentown upper Cambrian (Ozarkian of Ulrich) limestone, but possessing rather a fauna closely allied to that of the Beekmantown limestone of New York localities. Nevertheless, the term Kittatinny was retained to include this as well as the Cambrian limestones already described.[18]

Description.—The rock is a blue-gray dolomitic limestone, slightly darker than the Allentown formation. It is more massive below, more thinly bedded above, and becomes progressively leaner in magnesia upward. Edgewise conglomerate, consisting of slender fragments of buff-colored, finely crystalline dolomite, which weathers to a light gray, set in a matrix of dark, occasionally fetid, more coarsely

[17]Ulrich, E. O., Op. cit., p. 620.

[18]Weller, Stuart, The Paleozoic faunas: New Jersey Geol. Survey, Report on paleontology, vol. III, p. 15, 1903.

crystalline limestone is seen in some beds. A siliceous "wash", forming on the weathered surface a fine, buff-colored or dark network, is characteristic. These two features are not lacking in the Allentown limestone, and thus are a source of confusion, but the more highly calcareous nature of the Beekmantown serves to distinguish the two lithologically.

In an open field, about half a mile south of the Portland post-office and 1,000 feet west of the Delaware River highway, four quarries have been cut into limestone. Of these the northermost yielded a fauna of Canadian or Upper Ozarkian age and thus represents the formation as here described.

This quarry shows three types of dolomitic limestone, alternating with each other. Some of the limestone consists of beds three feet thick, showing edgewise conglomerate. On the fresh surface the color is uniformly blue-gray, the matrix slightly darker than the fragments of conglomerate; upon weathering the edgewise conglomerate fragments alter to bluish while the matrix becomes a dirty brownish-gray. Interstratified with this type of rock is a highly oolitic and slightly fossiliferous, blue-gray magnesian limestone, which weathers a light blue-gray. Fossils were collected from a thin, somewhat argillaceous bed in this limestone facies. This second type of rock makes up the greater portion of the middle of the exposure, but alternates irregularly with the more massive type first described.

It passes by almost imperceptible gradation into massive dolomitic limestone, light stony-gray in color, in beds three feet think.

About ten feet above the bottom of this exposure a bed containing poorly preserved fossils was found. A collection was submitted to the paleontologists of the United States Geological Survey for indentification. Mr. C. R. Resser, after a brief examination, pronounced them Beekmantown in age. Mr. E. O. Ulrich reports the following forms:

Eoorthis gasconadensis, Ulrich, *Ophileta minnesotensis,* Sardeson, *Gasconadia patilla,* Sardeson.

Ulrich would refer this limestone to the upper Ozarkian, —probably Gasconade or Oneonta. It would thus lie slightly lower than the typical Beekmantown of the Champlain Valley, if Ulrich's interpretation of stratigraphic equivalents be accepted[19].

This formation is not distinguished on the basis of topography alone from the Allentown and Tomstown limestones.

The formation is between 1,000 and 1,500 feet thick.

Age and correlation.—The fauna at the one locality mentioned (Columbia, N. J.) consists of fifteen species, mainly trilobites and gastropods, —a typical Canadian assemblage. Similar, but smaller assemb-

[19]Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. Am., Bull., vol.22, p. 27, 1911.

lages are to be seen at Catasauqua,[20] Pennsylvania, where pleurotomarids, *Maclureas*, and orthoceratids have been found by several geologists.

This limestone has been called by Peck and others the Coplay limestone[21], but as it is clearly the local equivalent of the Beekmantown of New York both lithologically and faunally, the practice of Miller[22], and Stose[23], and others may as well be followed and the name Beekmantown retained.

Miller mentions the finding in this formation of a small fauna including the following:

Helicotoma sp.
Syntrophia lateralis
Protowarthia rossi
Liospira (?) sp.
Ophileta complanata
Eccyliopterus volutatus

—an assemblage correlated by Ulrich with the Beekmantown of New York[24].

This represents the lowest Ordovician sedimentation recorded in the region. The boundary line between this and the Allentown limestone being recognizable with difficulty where at all, the Beekmantown limestone, also, has not been separated from the underlying calcareous sediments in the preparation of this report.

Jacksonburg Limestone

Description.—The Jacksonburg formation, also called Trenton limestone by Weller[25], because it contains characteristic Trenton fossils, is found above the Beekmantown magnesian limestone and below the Martinsburg shale. It can be separated into two parts, designated by Peck[26] the Nazareth and Lehigh limestones; Miller prefers the names Nisky and Nazareth limestones[27]. The second name mentioned in both cases is applied to the younger part of the formation. The lower part varies from fine, rather even grained, light colored to coarsely crystalline, black limestones. It is approximately 75 feet thick. At the base this rock contains fragments of the underlying dolomite, either in the form of larger boulders or as "fine, clastic material apparently derived from the underlying Kittatinny limestone."[28] Such

[20]Walcott, C. D., Notes on the Cambrian rocks of Pennsylvania from the Susquehanna to the Delaware: Am. Jour Sci., 3d ser., vol. 47, p. 30, 1894; Peck, F. B., Preliminary report on the talc and serpentine of Northampton County, etc.: Pennsylvania Top & Geol. Survey, Report No. 5, p. 27, 1911.

[21]Peck, F. B.: Op. cit., p. 27.

[22]Miller, B. L., Personal communication, 1923.

[23]Stose, G. W., U. S. Geol. Survey Atlas. Mercersburg-Chambersburg folio (No. 170), p. 6, 1909.

[24]Miller, B. L., The mineral pigments of Pennsylvania: Pennsylvania Top. & Geol. Survey, Report No. 4, p. 19, 1911.

[25]Weller, Stuart, Op. cit., p. 16.

[26]Peck, F. B.: Op. cit., p. 27.

[27]Miller, B. L., The mineral pigments of Pennsylvania: Pennsylvania Top. & Geol. Survey, Report No. 4, p. 15, 1911.

[28]Weller, Stuart: Op. cit., p. 17.

conglomeratic phases are to be seen in a pit south of Portland, Pennsylvania. This lower part of the Jacksonburg or Trenton limestone is very pure and has been extensively quarried for lime, although occasional beds are much higher in magnesia content.

At Jacksonburg, New Jersey, the type locality, the fossils of this rock were carefully studied by Weller.[29] Here it was found that the lower 58 feet, apparently corresponding to Peck's Nazareth limestone, bear a fauna distinct from the upper 63 feet and of Black River age.

The upper part of the Jacksonburg limestone contains a Trenton fauna.[30] The rock varies from drab or light gray to a dark blue-gray, almost black color; the latter predominates and is especially characteristic near the top of the formation. Shaly fracture is not uncommon, but in places sericite has formed and well developed cleavage is seen, so that the beds break "into broad flat pieces, having a distinct iridescent sheen in the cleavage surface" which Peck attributes to flakes of graphite.[31] Considerable difficulty is in fact encountered in the field in distinguishing between these uppermost, dark beds of the Jacksonburg and the overlying slate, because they are alike in color, in the hue assumed on weathering, and in the possession of a fairly well developed cleavage. Application of acid, however, distinguishes them at once, as the Jacksonburg limestone effervesces readily. Physiographically, too, a line may be drawn at the top of the Jacksonburg, as its ready yielding to the solvent action of water develops a slight bench below the level of the slate hills to the north.

The upper part of the Jacksonburg limestone, the Lehigh limestone of Peck, has a thickness the estimates of which vary between 500 feet[32] in eastern Pennsylvania and 63 or 83 feet [33] at the type locality in New Jersey.

At Portland a small quarry measuring 150 by 70 feet lies 220 feet south of that already described as exposing a limestone of Beekmantown or slightly greater age. About 100 feet south of this quarry in turn is another of about the same dimensions. This shows twenty feet of pure limestone in flaggy beds three feet thick at most and more commonly only attaining a thickness of six inches. Some of the beds are oolitic. Dark, well-formed calcite crystals are scattered throughout the rock and the fresh surface effervesces readily in acid. The beds are highly fossiliferous, but the species are few. Mr. Ulrich reports the identification of the following species:

Stictoporella exigua, Ulrich, *Phaenoporæ incipiens,* Ulrich, *Pachydictya acuta,* Hall, *Dinorthis pectinella,* Hall.

[29]Weller, Stuart: Op. cit., p. 16-38.
[30]Weller, Stuart: Op. cit., p. 37.
[31]Peck, F. B.: Op. cit., p. 30.
[32]Miller, B. L., The mineral pigments of Pennsylvania: Pennsylvania Top. & Geol. Survey, Report No. 4, p. 19, 1911.
[33]Weller, Stuart: Op. cit., p. 18 et seq.

He adds, "So far this association is known to occur only in a lower Trenton zone in the vicinity of Watertown, N. Y., the east shore of Lake Champlain, and near Montreal, Canada. * * * * At the Champlain and Canadian localities (it lies) in the limey basal Trenton with dark shale of Trenton age and of the Martinsburg type close above it." The sequence described by Ulrich appears to be in close agreement with that at Portland.

This formation forms a terrace about fifty feet lower than the top of the slate terrace proper. In many places its distribution can be mapped from this feature alone.

From what has been said, it is obvious that the Jacksonburg limestone attains a thickness of as much as 550 feet, of which the lower member is 50, the upper 500 feet thick. From this maximum, the formation dwindles in places to complete disappearance.

Age and correlation.—As already stated, these beds are partly of Black River, partly of Trenton age.

Martinsburg Formation

General description.—Upward the beds of the youngest member of the Jacksonburg limestone become more and more argillaceous and finally lose their calcareous content altogether. They are overlain by a shale, which, through pressure is in most places altered to a slate. To the stratigraphic equivalent of this formation in Maryland the name Martinsburg shale, suggested by Darton[34], has been applied[35]. The 10,000 feet or so of shale and slate above the Jacksonburg limestone are here given the same name because they appear to correspond stratigraphically, faunally, and lithogically with the Martinsburg formation as described in Maryland and New Jersey[36].

Although the Martinsburg shale is spoken of as grading downward through a gradual transition into the Jacksonburg limestone and the line between the two formations is difficultly drawn, it is believed that where exposures are adequate the boundary of the sericitic and noncalcareous beds which are at the base of the Martinsburg can be recognized with certainty.

The formation consists of a series of beds of shale, largely converted into slate, and sandstone, with occasional lenses of limestone near the base. By far the greater part is argillaceous, as even the sandy beds bear lenses and masses that were originally clay though now altered to sericite.

Three members can be distinguished, of which the total thickness measured in the Lehigh River section is 8,692 feet and in the Little

[34]Darton, N. H., Notes on the stratigraphy of a portion of central Appalachian Virginia: Am. Geol. vol. X, p. 13, 1892.

[35]Bassler, R. S., Cambrian and Ordovician: Maryland Geol., Survey, p. 49, 1919.

[36]Bayley, W. S., Salisbury, R. D., and Kummel, H. B., U. S. Geol. Survey Geol. Atlas, Raritan folio (No. 191), p. 11, 1914; Spencer, A. C., and others, U. S. Geol. Survey Geol. Atlas, Franklin Furnace folio (No. 161), p. 11, 1908.

Bushkill section, 15,745 feet. The average of these two sections, 12,218 feet, is probably too high, rather than too low an estimate.

By far the larger part of the Martinsburg formation is distinctly shaly or slaty in character. The lowest member is a siliceous and thin-bedded clay-slate where not highly altered, or a hard bluish-gray slate where metamorphism is more extensive; it contains occasional lenses of dolomitic limestone near the base, and becomes sandy higher up, thus passing into the middle member by a gradual transition. The middle member is highly siliceous, presenting quartzitic, clay-slate, and slate phases; the sandy beds are generally rich in carbonate of lime. The upper member consists of thicker beds of alternately more carbonaceous and more sericitic but originally argillaceous material now wholly altered to slate.

LOWEST OR HARD SLATE MEMBER

Description.—The lowest member is sandy, yet is clearly to be classed with slate, in that it is very highly argillaceous and in most exposures shows well-developed cleavage. The separate beds consist of alternating bands of more sericitic, more carbonaceous, and more siliceous material. An illustration is given in Plate III, A. Beds of the first type are wider, measuring generally from a quarter of an inch to three inches in thickness and rarely exceeding six inches. The more siliceous and the more carbonaceous bands are ordinarily less than half an inch, but may attain as much as four inches in thickness. Rarely this member shows thin lenses of calcareous sandstone; this effervesces in hydrochloric acid, although the slate itself does not effervesce at all. Such lenses are best seen in the railway cut along the west bank of Lehigh River a mile north of Cementon, outside the area mapped.

In color the slate is blue-gray, the more siliceous beds with a faintly silvery sheen, and the carbonaceous beds somewhat darker than the others. Upon weathering the rock becomes lighter in color and as the ferrous compounds are exposed to the air a very long time the characteristic gray color changes to buff and finally rusty brown and the slate breaks into smaller rhombic pieces or separates into many leaves no thicker than a sheet of heavy paper.

Even the soft rock in this member is harder than ordinary slate, so that the product has come to be known as "hard slate" among the quarrymen. The area in which it is exposed is called the hard belt.

As the boundary between a siliceous bed and the succeeding argillaceous layer is generally ragged, the bedding in its minute detail cannot be spoken of as regular. Nevertheless, in a larger sense it is remarkably uniform, marked thickening within short distances being rare. Yet instances of abrupt thickening and thinning are not wanting. Occa-

PLATE III

A. Typical hard slate, from lowest member of the Martinsburg formation; the block is 2.5 feet wide.

B. Soft slate, showing alternating carbonaceous and sericitic layers.

sional hand specimens six inches wide show an increase in a single bed from a thickness of one to one and one-half inches.

Half-way between Seemsville and Kreidersville a road leads southwestward from the highway connecting these two towns. Here, on the east side of the road, are sandy lenses, varying in length between three and eighteen inches, which break into subangular blocks and are stretched out parallel to the well developed slate which surrounds them. Although their present form is lenticular, it is thought that this feature is largely due to the squeezing effect of the pressure which simultaneously sericitized the original shale and tore apart the more sandy beds (see Fig. 2).

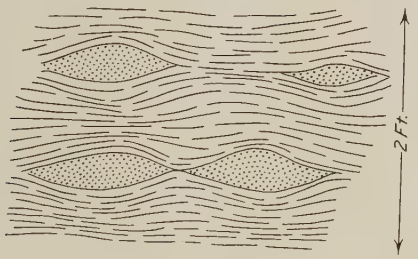

Figure 2. Sandy lenses in hard slate, exposed between Kreidersville and Seemsville.

For a description of the microscopic appearance of this member, see the section on the petrology of the slate (p. 88). The petrographic descriptions given for the slate apply almost equally well to any of the beds in this member although those portions worked for slate generally bear less silica than other, more sandy parts. Metamorphism has almost invariably highly sericitized the shale with the development of secondary cleavage, which, crossing the stratification, makes the bedding planes recognizable only with difficulty in thin sections. The cleavage planes are better developed in the originally shaly beds than in the intervening sandy layers.

In the northwestern part of the Allentown quadrangle, the lowest member of the Martinsburg shows unusual beds of thick limestone. These are well exposed at several quarries about a mile east of Seemsville and again in smaller openings along Catasauqua Creek, 1½ miles north of Weaversville. A section of such an exposure at a large quarry one mile S. 70° E. of Seemsville showed the following:

Section near Seemsville.

		Feet
9.	Surface soil filled with slate fragments	3
8.	Slate, dark blue-gray, iron-stained at the surface and along cracks; quartz-filled veins parallel to bedding and cleavage	6
7.	Limestone, massive, light blue-gray, magnesian, greatly shattered, with quartz veinlets	4½
6.	Slate with a few thin lenses of limestone	3
5.	Limestone, thin beds with small amounts of interbedded slate; some of the limestone white, crystalline, with a fetid odor when broken	3
4.	Limestone, massive, blue-gray, magnesian, considerably shattered	3
3.	Limestone, thin-bedded, some layers slightly contorted	1½
2.	Limestone blue-gray, magnesian, in fairly thick beds	4
1.	Limestone, massive, magnesian, in which stratification is poorly shown; not fetid; blue-gray, finely granular	18
		46

Cryptozoon were observed in some loose blocks, but none was seen in place. Although there is a sharp line separating bed 8 from bed 7, this is clearly not a fault contact and the relations present the appearance of a continuous sequence from top to bottom.

Similar relations between typical hard slate above and massive dolomitic limestone below are seen in an abandoned quarry south of a farm house 0.6 mile due west of Seemsville in the Allentown quadrangle.

Again, as the road along the east bank of Catasaqua Creek is followed northward from the main highway between Nazareth and Howertown, the low topography characteristic of the Jacksonburg limestone is left behind and about 750 feet north of the highway slate is seen in the road cut. Fifty feet farther north, blue-gray, fine-grained, dolomitic limestone is exposed. Similar rock, but partly lighter in color and fetid when broken open, is seen in the stream valley to the west, but about 100 feet north, slate outcrops in the road.

From this and similar occurrences it is evident that the appearance of irregularly distributed lenses of blue-gray magnesian limestone and white, more coarsely crystalline, and fetid limestone are not to be attributed to deformation but to variations in primary sedimentation during early Martinsburg time. Quarries in the area mapped at which such limestone is exposed are located at the following places in addition to those already mentioned:

1. A quarry north of the road between Kreidersville and Seemsville and 0.2 mile west of the latter village.
2. Two quarries in the hill slope east of the church that is 0.8 mile east of Seemsville. These two quarries are about 600 feet apart.
3. A large opening on the west side of the road along Catasauqua Creek, half a mile north of the Nazareth-Howertown highway.
4. A small opening 1,000 feet west of the last site mentioned.
5. A small opening exposing a bed of the white, fetid limestone 600 feet east of site 3, above; this pit is on the hillside east of the main valley and north of the small stream which here enters Catasauqua Creek from the east.
6. Two small openings on the hillside east of Catasauqua Creek 0.8 mile southeast of Seemsville.

In at least one instance folding, which must have antedated the development of cleavage, was seen in the hard slate. On the dump of the Graber quarry, about a mile due west of the Chapman quarries, a

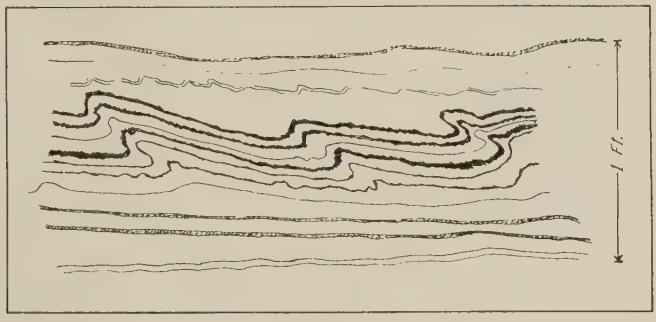

Figure 3. Sketch of block of slate, showing folding previous to the development of cleavage. The surface of the page is parallel with the cleavage. Graber quarry.

block measuring three feet by one foot was found showing drag-like, minor folds affecting a series of beds about six inches thick and bounded above and below by undisturbed strata (Fig. 3). Such folds were probably formed while the muds were being deposited.

The lowest member of the Martinsburg formation is best studied in the slate quarries. Extensive exposures have also been made by road cutting on the Bangor highway along the first two miles north of Martins Creek, on the west bank of Delaware River one mile north of Belvidere, and along Bushkill Creek from Haynes Mill to Belfast.

The hard slate underlies surfaces which rise to 200 and 300 feet above

the limestone valley. This member forms the front of the slate terrace and a southward facing escarpment marks its southern boundary.

The severe contortions of the strata and the difficulty encountered in attempting accurate restoration of the structure where recumbent folds are so common, as well as the intense thickening and thinning actually observed in small exposures, suggest that the most careful measurements of thicknesses are to be regarded as scarcely better than estimates. The thickness of detailed sections of the lowest (hard) member of the Martinsburg formation measured along Little Bushkill Creek is 5,630 feet, and along Lehigh River is 4,262 feet. The average of both measurements is 4,946 feet.

These two sections are much alike. On Delaware River the lowest (hard slate) member of the Martinsburg is about 5,210 feet thick.

Age and correlation.—There is no conclusive evidence as to the exact age of this member in the region here discussed. Though diligently searched for, no fossils were found. The severe compression to which the shale was subjected and the consequent recrystallization prohibit the preservation of fossils at any place except where cleavage and bedding are strictly parallel. A few graptolites have been found in what appears to be the stratigraphic equivalent of this member of the Martinsburg in the neighborhood of Harrisburg. In New Jersey, where the three members of the formation have not been differentiated, a fossiliferous locality in the vicinity of Branchville, Sussex County, "a short distance above the Trenton limestone" is described by Weller.[36] The rock in which the collection was found is not described and a fault, the throw of which is not given, lies between the Trenton (Jacksonburg) limestone and the slate, but the fossils were collected in a quarry and the probabilities are that these represent the slate-bearing beds of the lower member. The fauna includes:

Diplograptus foliaceus, Murch. *Lasiograptus mucronatus*, Hall.
D. angustifolius, Hall *Corynoides calycularis*, Nich.
Dalmanella testudinaria, Da.

This fauna is said by Weller to show Normanskill relationships. At Jutland, Hunterdon County, New Jersey, a somewhat similar assemblage of graptolites, also of Normanskill affinities, was found in beds that, from their areal relations to the older formations, appear to represent the lower member of the Martinsburg[37]. More recently Ulrich has assigned these fossils and their containing beds to Trenton time[38].

In Maryland the lithologic sequence does not closely resemble that given in this report, and correlations between the formation in Maryland and the Northampton County, Pennsylvania, occurrences are not

[36]Weller, Stuart, The Paleozoic faunas: Report on paleontology, vol. III, Geol. Survey of New Jersey, p. 52, 1903.

[37]Weller, Stuart: Op. cit., p. 53.

[38]Lewis, J. V., and Kummel, H. B., The geology of New Jersey: New Jersey Geol. Survey, Bull. 14, p. 47, 1915.

possible on the basis of observations yet made. Attention is directed, however, to the fact that a lowest division of Trenton and Utica age is recognized[39] on the basis of numerous fossils.

These observations agree in general with a statement by Ulrich in a personal communication, "According to present views, the Martinsburg shale includes beds of Trenton age in its lower part."

Rather than apply a special name to this member of the Martinsburg formation, the term lowest member or hard slate member will be used in this report. Ultimately, however, after conferences with stratigraphers acquainted with this region, it is proposed to designate this and the superjacent divisions with locality names.

MIDDLE OR SANDY MEMBER

Description.—The middle member consists of beds of sericitic slate, less completely altered clay-slate, and occasional relatively thick beds of sandstone. The line between this and the lower member of the Martinsburg is hard to draw, as it is a matter of judgment when beds of sandy slate less typical of the lower member bear sufficient sand to warrant placing them with the overlying subdivision. It may be remarked, in passing, that this uncertainty in delimiting the middle member is doubtless one of the causes for the variations in estimates of its thickness from place to place.

The beds most characteristic of the sandy member of the Martinsburg formation are blue-gray sandstone in part cross-bedded, which, upon weathering, develops a buff-colored, sandy surface. The fresh specimen almost invariably effervesces with hydrochloric acid, but is readily leached of its lime content when exposed to surface solution. Stringers and lenses of clayey matter are not uncommon in these beds, and thin layers of dark, apparently highly carbonaceous slate occur between the thicker beds. These more slaty beds not uncommonly show fracture cleavage (slip cleavage, false cleavage) along planes striking parallel to the true cleavage but dipping far more steeply. They weather into alternate bands of buff and light blue-gray, sandy slate, showing very conspicuous banding. As this member is notably arenaceous, the soil above it is commonly highly sandy, in contrast with that formed from other portions of the slate formations, and bears upon it chips or even blocks of porous sandstone of a shade about that of cured tobacco. Such fragments differ noticeably from those of the more truly slaty members of the formation in that they are more nearly equidimensional, a fair representation of their form being given by a block measuring 1 by 3 by 3 inches, whereas the flakes from the more slaty members more commonly measure, for comparable surfaces, say, a quarter of an inch in thickness.

In addition the remarkable resistance of these beds to erosion, in com-

[39]Bassler, R. S., Cambrian and Ordovician: Maryland Geol. Survey, p. 157, 1919.

parison with the slate, is such that the area underlain by them generally rises 50 to 60 feet above the general level of the country, the surface declining both to the north and south. The general region underlain by this member of the Martinsburg formation is thus recognizable superficially by its greater relief, and upon close scrutiny of the surface by the many chips that are mixed with the sandy soil. Care must be used, however, in applying these criteria.

The typical appearance of the beds of the middle member can best be seen in the cut of the Delaware, Lackawanna and Western Railroad, a quarter of a mile south of Ramseysburg on the eastern side of Delaware River, and again three-quarters of a mile north of the village of Delaware on the same side of the river. They are also well exposed along the Slate Belt Electric Railway half a mile north of the Central School, which is 3 miles south of Wind Gap.

The uppermost portion, probably representing 250 feet in thickness —which, however, could not be accurately measured, because nowhere continuously exposed —is exceptionally massive sandstone in beds up to three feet thick. The rock is of a moderately dark slate-gray color, weathering to a light tobacco brown. It consists of a fairly clean sand, between the grains of which are ferruginous calcite and dolomite. Even in this rock, compression has been so severe as to produce sericitization, in places to such an extent that cleavage, rather than bedding determines the form of isolated blocks. Layers of slate 4 inches or less in thickness locally separate the more quartzose strata.

These beds are seen in the Slatington quadrangle where the Lehigh and New England Railroad tracks cross those of the Lehigh Valley Railroad about three-quarters of a mile south of the station at Slatington; this outcrop, however, lies beyond the boundaries of the area here described. Apparently the same series of beds is exposed on the slope rising southward about a quarter of a mile south of the East Bangor postoffice.

In sediments laid down in relatively shallow water, where sandy and clayey laminae or lenses alternate in close succession and where, in addition, the beds have been badly contorted, the correlation of strata over large areas is fraught with serious difficulties. This is especially true where, as here, metamorphism has obliterated records of life, and where outcrops are rare. It should be born in mind also that much minor thrusting presumably took place when the Martinsburg slate suffered its severe deformation and that these more sandy layers may well have sheared over the intervening plastic clays, so that faulting here with gap, yonder with overlap, and elsewhere even with several repetitions is not improbable. Nevertheless, the rough continuity of the upper, exceptionally sandy beds appears to be not improbable.

Locally similar rock is seen elsewhere at stratigraphically lower

horizons. Thus a quarter of a mile northwest of Kreidersville (Allentown sheet) in the valley of Indian Creek and east of the bridge, large blocks of blue-gray calcareous sandstone are exposed. Again, along the Slate Belt Electric near Central School, in the locality already mentioned above, some outcropping beds are exceptionally thick and very sandy. About 1¼ miles north of Chapman Station on the Lehigh and Lackawanna Railroad, massive sandy beds occur. There is, in fact, a strong suggestion that massive sandy beds characterize the lowest part of the middle member of the Martinsburg, just as they also mark the uppermost portion, with more slaty layers between. Heavy sandstone with thin beds of shale are also seen in the valley of Hokendauqua Creek about a mile S. 45° E. from Youngsville (Wind Gap sheet) and on the road between Emanuelsville and Point Phillip, three-quarters of a mile east of the former town.

Occasionally lenses of slate of sufficient thickness and cleavability to have been worked in the past, appear in the belt of country underlain by the middle member of the Martinsburg formation. The slate is said to be somewhat softer than hard belt slate, and it has the papery weathering characteristic of the slate of Pen Argyl and Bangor but the beds are thin and the "ribbons" too close together to justify mapping it in the soft belt. The two small areas in which this slate has been quarried are therefore separately indicated. One is the Batt quarry, one mile southwest of Millers, Wind Gap quadrangle; the other is an old opening now filled, about a mile west of Johnsonville in the Delaware Water Gap area.

Of the members of the Martinsburg formation these sandy beds are the most resistant to erosion. The land under which they lie therefore rises to elevations of 600 feet in the neighborhood of Delaware River and even to 850 feet in the western part of the Wind Gap quadrangle, so that the summits differ in altitude from the general elevation of the hard and soft slate belts to the south and north by as much as 75 or 100 feet (See Plate I, C and IV, A). Steep cliffs, narrow gorges, and small rapids mark the course of the streams through this sandy belt of the Martinsburg.

The thickness of the middle member of the Martinsburg formation was measured along the Little Bushkill Creek and along Lehigh River. The former section gave a thickness of 5700 feet, while the thickness on the basis of measurements made in the latter section was 2720 feet. As these measurements are only the best approximations available, because of the discontinuous exposures and the severe folding, the actual thickness may be assumed to lie somewhere between the two. In a general way it appears that beds of the massive, calcareous sandstone in this member become more numerous westward, and that, moreover, the entire sandy member of the Martinsburg formation gains greater thickness in that direction.

PLATE IV

A. Topography typical of the lower hard slate member; looking north toward Whitesell quarry from Northampton Electric Railway tracks; Blue Mountain is in the background.

B. Stripping of glacial till 15 feet thick at Columbia Bangor quarry.

Age and correlation.—Of the three members into which it is possible to separate the Martinsburg in this region, only the middle member yielded fossils and even these were in a poor state of preservation. So extensively metamorphosed is this rock that even here the merest traces of organisms are all that remain. A small collection made

west of the area mapped, but in beds that are unquestionably the westward continuation of the middle member, was sent to the United States Geological Survey. Mr. E. O. Ulrich reported that the impressions were too imperfect for positive identification but that they are probably valves of an Upper Ordovician orthoid. The specimens were collected 5 miles southwest of Slatington from a locality one mile west of Newside (Layton Farm).

Of the four subdivisions of the Martinsburg recognized in Maryland, the lowest, as already mentioned, is of Trenton and probable Utica age, the second of Eden, and the third of lower Maysville age. If the lowest division in Maryland corresponds to the lowest member of eastern Pennsylvania, the Maryland equivalent of the Eden would seem to be at least in part correlated with the middle, sandy member of the Martinsburg as seen in Northampton county. Lithologically, however, the resemblance between the latter and the lower Maysville correlative in Maryland is striking.[40] It is not impossible that the middle, sandy member of the Martinsburg in eastern Pennsylvania is thus of Eden and lower Maysville age.

In the Mercersburg region of southern Pennsylvania, Stose[41] reports a two-fold division of the Martinsburg formation, the upper member corresponding lithologically to the Maryland Eden and bearing a similar, though not identical fauna.

In New Jersey, Weller[42] long ago inferred that the "Hudson River shale", now called Martinsburg, is the time equivalent in part at least of Utica and Lorraine. His conclusions, therefore, are not in opposition to referring the middle, sandy member of the Martinsburg to Eden age, which is here accepted.

No special name derived from the type locality is applied to this member. The beds included in it are here referred to as the middle or sandy member of the Martinsburg formation.

UPPER OR SOFT SLATE MEMBER

Description.—The uppermost member of the Martinsburg formation is a banded rock, showing thick beds of light bluish-gray slate alternating with thinner beds of almost black slate; between these more typical slate beds are occasional sandy layers, somewhat calcareous. Considerable thicknesses of the more sandy beds are seen, but these are much less in the aggregate than the more strictly slaty strata.

In detail the thicker beds of slate are for the most part of a light blue-gray color, without, however, being uniformly of one shade. There are, in fact, all gradations between a light blue-gray slate and an al-

[40]Bassler, R. S., Cambrian and Ordovician: Maryland Geol. Survey, p. 157 & pp. 167-168, 1919.

[41]Stose, G. W., Mercersburg-Chambersburg Folio: U. S. Geol. Survey, Geol. Atlas of the United States, Folio No. 170, p. 10, 1909.

[42]Weller, Stuart, A preliminary report on the Paleozoic formations of the Kittatinny valley in New Jersey: Geol. Surv. of New Jersey, Ann. Rept. for the year 1900, pp. 5-7, 1901.

most coal-black. Two beds of greenish-gray chloritic slate are constant features in the series and serve as horizon markers: although of an unusual olive-green color on fresh fracture, they become a conspicuous light slate-gray on weathering and are known by the quarrymen as the gray beds. These and the more typical light slate-colored beds alternate with the darker, more carbonaceous layers, called ribbons by the quarrymen, so that an exposure of such slate bears a banded appearance, formed by alternate light and dark beds. This is illustrated in Plate III, B.

There is a strong suggestion of relation between the dark and light beds. It was thought in the beginning of these studies that an abnormally thick, dark bed normally followed each thicker band of light-colored slate or big bed, but this cannot be unequivocally substantiated when accurate measurements are taken. Thus, twenty-five carefully measured sections yielded the following results:

	Number of cases
Thick, light bed preceded by thick, dark bed	3
Thick, light bed followed by thick, dark bed	10
Thick, light bed not associated with thick, dark bed ...	12

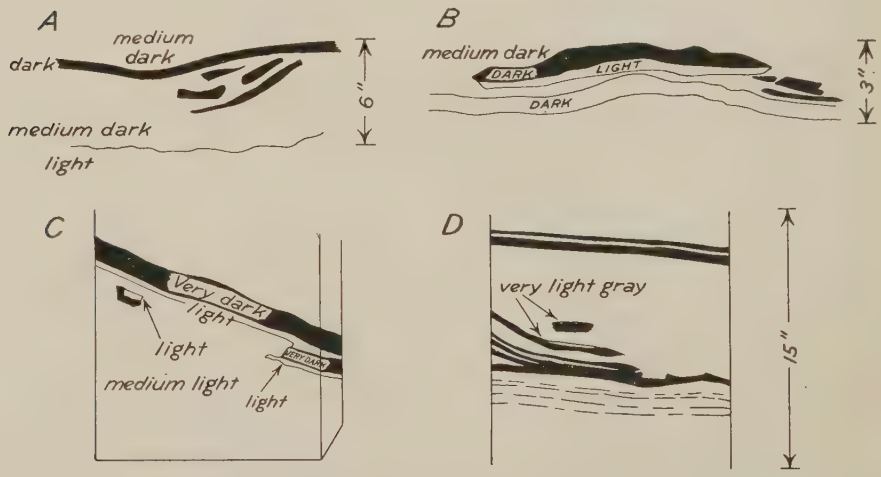

Figure 4. A-C. Sketches showing irregularities in bedding in the carbonaceous layers in slate suggestive of intraformational conglomerates; B. is from the Bangor Central quarry, A and C from the North Bangor quarry. D. Irregularities in slate from Consolidated No. 1-Star quarry. All unshaded parts are of normal light slate color, except as indicated.

In places, flakes of the darker beds are enclosed like the fragments of an edgewise conglomerate, in a matrix of a lighter color. This is well illustrated in the North Bangor and Bangor Central quarries. Examples are shown in the sketches in Figure 4. These cases are divisible into two groups,—one in which the isolated pieces are len-

ticular and the subjacent beds show no gaps into which they might fit, the other where the isolated pieces are sharply angular at their ends and appear torn from their original position by slight tectonic movements. Both of these types of fragments are illustrated in the drawings. They may be due to one of three processes: (1) small-scale faulting after all the beds were well consolidated and had long been laid down, (2) irregularities in primary deposition, or (3) slumping or other settling movements incidental to primary deposition but taking place after sufficient hardening of the deformed layers to permit them to act as competent beds. In most cases the latter seems to be the best explanation, but the occasional flakes of black, highly carbonaceous material which lie in places imbedded in slate of a totally different color and nature may represent mere irregularities in deposition.

Scattered throughout the sequence of this upper member are relatively thin beds of calcareous sandstone, contrasting in massiveness with the better cleaving slates. These rarely approach the heavier slate beds in thickness. They present the appearance in miniature of the basal sandstone that should be anticipated beneath a shale where the order of sedimentation is that consonant with an encroaching sea. The quarrymen call such sandy layers hard rolls, because of their resistance to steel. They are almost invariably followed in deposition by exceptionally thick beds of the lighter-colored phase of slate, as though there were indeed a genetic relation between the two. This relation is shown in the following table of some typical thickness measurements:

Comparison of thickness of slate and sandstone layers.

Name of bed	Light gray slate part	Basal sandy part
	Inches	Inches
Big bed, Albion-Bangor quarry	60	4
Big bed, Phoenix quarry	58	7
Big bed, Phoenix quarry	50	3
Red bed, New Diamond quarry	98	9
Big bed, Northampton quarry	97	15
Big bed, Northampton quarry	82	31
Middle big bed, Columbia Bangor quarry	121	9
North Bangor No. 3 big bed, Bangor Vein quarry	153	35

Occasionally, as in the case of the Genuine big bed, Parsons quarry, an alternation of light and dark beds intervenes between the thick, light gray and the sandy beds. Again occasionally a thinner "hard roll" will be followed by an unexpectedly thin bed of light-colored slate. These are, however, exceptions.

Not uncommonly the sandy beds just described show well-developed

cross-bedding, especially when weathered. A striking feature is the generally westward dip of the cross-bedding. A sketch of a slab showing such cross-bedding is presented in Figure 5, A. This evidence

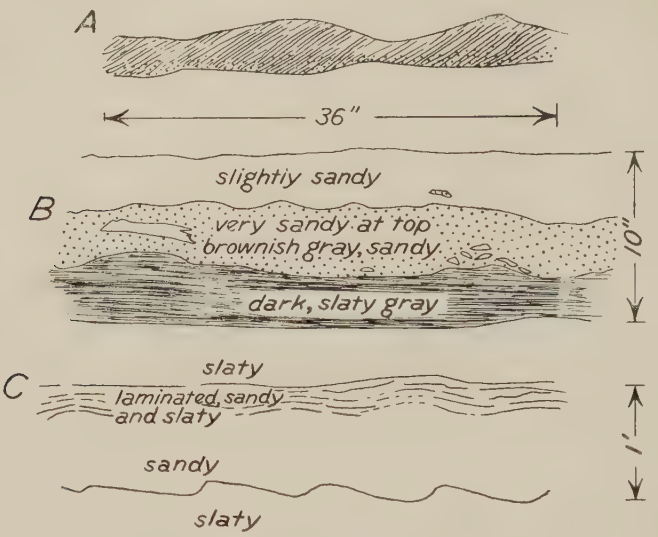

Figure 5. A. Sketch showing cross-bedding in sandy layers in slate; the laminae dip west; Phoenix quarry. B. Sketch showing irregularities in bedding suggesting shallow water deposition; slate from the Consolidated No. 1-Star quarry. C. Ripple marks in sandy layers; the beds are inverted; the current came from the left (east); Bangor Vein quarry.

of the shallow-water origin of the sandy layers is well shown in most of the "hard rolls" of the soft belt quarries. Other sandy beds show current ripple-marked upper surfaces, as is seen in Figure 5, C the currents having come from the east.

As the sandy layers are not greatly recrystallized, because of the high quartz content, cleavage in them is only poorly developed in comparison with that in the slate.

In one case a minor unconformity of an intraformational nature was observed in a loose block, as shown in Figure 6.

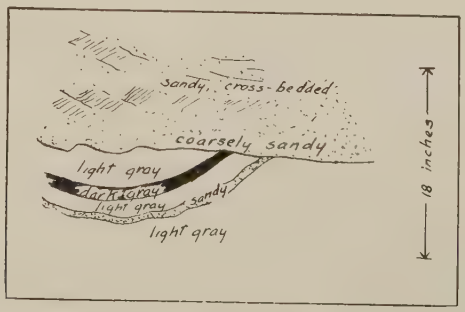

Figure 6. Intraformational unconformity in block of slate from Kinney quarry.

Locally in this uppermost member of the Martinsburg formation there are beds of pure calcite, now coarsely crystalline. They are generally very thin, seldom more than half an inch. The quarrymen speak of them as silver ribbons or, when the slate breaks parallel to them, as loose ribbons. Rarely, as in the bottom of the Jackson-Bangor No. 6 quarry, have they been minutely fractured. These calcareous laminae are important from the structural viewpoint because movement between beds commonly took place along such "silver ribbons". Further, as solution dissolves out the calcite, an open plane is left along which water enters the quarry; this extensive crevice furnishes a gliding surface along which slate from the walls may fall into the excavation,—a grave danger to the quarrymen.

Microscopically the slates of the soft belt were examined with considerable care. A detailed description of their microscopic petrography is given under the section on the petrology of the slate.

By studying in detail the beds laid bare in the quarries, it has been possible to divide the uppermost member of the Martinsburg formation into two parts. These are shown on the areal maps. As the lower part has been quarried at Bangor, it is distinguished as the Bangor division, for which the term "beds" has been retained. The upper part is exposed at Pen Argyl and is best designated as the Pen Argyl beds. The term beds is retained, in place of the better technical term member, because its use avoids confusion with the larger divisions of the Martinsburg formation.

The slates of the Bangor beds are slightly harder than those of the Pen Argyl beds and do not attain such great thickness. Otherwise differences, both megascopic and microscopic, are lacking and the distinction in areal mapping depends wholly on careful measurements of thickness or on the recognition of the few key horizons that are furnished by the thickest slate beds. Detailed measurements are given in the section on the economic geology of the slate.

The two sets of beds are separated by a somewhat more sandy phase of sedimentation. This arenaceous series is shown on Slateford Creek, about a mile west of Slateford, and again by the few exposures and chips south of Wind Gap. These intervening beds are difficultly recognized; they are assigned to the Bangor beds, but the location of the boundary line between the two groups of beds as drawn on the map is a fair estimate at best. A more detailed description of the sequence is included in the section on the economic geology of the slate (pp. 105-106).

The soft belt is characterized by its depression between Blue Mountain to the north and the summits of the section underlain by the sandy member to the south. The soft belt, indeed, forms a broad longitudinal valley, with poorly developed drainage lines and even some swamp land; this valley is parallel with Blue Mountain. Its northern edge

rises into indefinite terraces having altitudes of about 800 feet, but these are very largely covered with talus from the quartzite cliffs of Blue Mountain.

The debris from the crest of Blue Mountain everywhere hides the upper edge of the Martinsburg slate in the area studied. Only at the Lehigh gap, west of the section here described, can the contact between the Shawangunk and Martinsburg formations be observed. Estimates of the thickness of the entire upper member are therefore unsatisfactory. Along the Little Bushkill the thickness measured from the top of the middle, sandy member of the Martinsburg to the base of the Shawangunk conglomerate appears to be 4,415 feet, but the section is largely concealed and variations in dip or repetitions in faulting may have introduced an error with an overestimation of fifty per cent. Along Lehigh River, where there is almost certainly some repetition by folding, the estimated thickness of the uppermost member is 2110 feet. There is an angular unconformity above the Martinsburg formation, which may account for at least a part of the discrepancy between the two observations. At best, however, these estimates cannot be accepted as wholly satisfactory.

Age and correlation.—No fossils were found in the soft slate member of the Martinsburg formation. In New York, near the New Jersey state line, Utica graptolites have been found close to the overlying Shawangunk conglomerate.[43] In Maryland, on the other hand, both lower and upper Maysville zones are recognized in the Martinsburg formation between the Eden and the Juniata.[44] This is what might be expected if an unconformity exists above the Martinsburg formation. In the Mercersburg-Chambersburg region the uppermost fauna of the Martinsburg formation is of Eden age.[45] In 1911 Ulrich correlated the upper Martinsburg shale in the "northeastern Pennsylvania basin" with the Eden-Utica of New York.[46] This interpretation was accepted by Grabau[47] who adds, however, that the fossils on which it is based occur well down in the section and hence that the upper beds may well be higher than Utica,—possibly even lower Maysville in age.

Reasoning wholly on the basis of comparative thicknesses, as the only evidence available, it appears best to assume that the upper member of the Martinsburg, as here defined, is of lower Maysville age.

These beds are here referred to as the upper or soft slate member of the Martinsburg formation.

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[43]Lewis, J. V., and Kummel, H. B., The geology of New Jersey: Geol. Survey of New Jersey, Bull. 14, p. 47, 1915.

[44]Bassler, R. S., Cambrian and Ordovician: Maryland Geol. Survey, pp. 157, 170, 1919.

[45]Stose, G. W., U. S. Geol. Survey, Geol. Atlas, Mercersburg-Chambersburg folio (No. 170), p. 10, 1909.

[46]Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. Amer., Bull., vol. XXII, p. 27, 1911.

[47]Grabau, A. W., Paleozoic delta deposits of North America: Geol. Soc. Amer., Bull., vol. XXIV, p. 420, 1913.

SILURIAN SYSTEM

Shawangunk Conglomerate and Sandstone

Description.—The Shawangunk conglomerate is a hard, partially recrystallized quartzite, in places highly conglomeratic. The pebbles, firmly fixed in the sandy matrix, are generally well rounded and consist of fragments of vein quartz, black flint, and sericitic slate, the last with its cleavage unoriented. With the hand lens the sand grains appear to be smooth and well worn and the conglomerate and sandstone are highly indurated. Cross-bedding is not uncommonly observed, and west of Lehigh River, north of the town of Slatedale, ripple marked slabs ten feet in diameter were observed in the talus slope at the foot of Blue Mountain. Stylolites were seen in the rock in the Delaware Water Gap.

In color the fresh surface is a light gray, reddish-brown, or even white, but on weathering the exposure rapidly acquires a dirty gray or brownish-gray hue or even turns a somber dark gray.

The beds of the Shawangunk conglomerate are massive, attaining a thickness of six feet. They are widely jointed and stand out in vertical cliffs which are flanked by heavy talus slopes, especially on the up-dip side. In places, as within the Delaware water gap and at its southern end, highly carbonaceous beds of shale are intercalated between the coarser, cross-bedded sandstone. These show incipient slaty cleavage.

The crest of Blue Mountain is made up of the Shawangunk conglomerate. It stands out in bold relief above the slate belt to the south, rising at the Big Offset to its highest altitude, 1640 feet above the sea. A steep slope, talus covered, faces southward, concealing its contact with the Martinsburg formation. Immediately north of this slope lies an almost flat table land, only half a mile wide at most, yet maintaining an altitude which varies but slightly beyond the limits of 1400 and 1500 feet.

The thickness of Shawangunk conglomerate was not measured in the course of these studies as the map area was drawn merely to the crest of Blue Mountain.

Age and correlation.—No large space can here be devoted to the consideration of the age of the Shawangunk conglomerate. A brief summary of the opposing views is, however, justified.

In New York the beds overlying the Pulaski shale (which is the last formation bearing a clearly Ordovician fauna) are, in descending order:

Upper Medina	—	white sandstone
Lower Medina	—	red sandstone
Oswego sandstone	—	gray sandstone

In the Lehigh and Delaware water gaps the following measurements were made by the staff of the Second Pennsylvania Survey:[48]

Lehigh Water Gap	Feet	Delaware Water Gap	Feet
Medina:		Medina:	
Upper sandstone	85	Upper sandstone	200
Ferruginous shales	180	Upper shales	530
Middle gray sandstone ..	70	Lower sandstone	200
Ferruginous shales	330	Lower shales	110
Oneida:		Oneida:	
Sandstone and conglomerate	290	Upper gray sandstone ...	75
		Shales with sandstone beds	240
Massive conglomerate ...	170	White conglomerate	210
	1125		1565

In New Jersey similar divisions and thicknesses are observed and here the formation is referred to as the Shawangunk conglomerate.[49]

Grabau has regarded the Oneida and its equivalent, the Oswego of New York, as of Lorraine age. As it is overlain by the Juniata-Queenston in Pennsylvania and New York, and as the Queenston is of Richmond age, the Oswego must be of Ordovician age, according to Grabau.[50]

This interpretation is certainly not accepted by Schuchert,[51] and Ulrich refers the Shawangunk of northeastern Pennsylvania to the Silurian, while regarding the Oswego (the equivalent of the lower Shawangunk) and Juniata (Red or Lower Medina) of Central Pennsylvania as of Ordovician age. In speaking specifically of the Shawangunk formation of Blue Mountain, Grabau[52] expressed the same opinion as that of Ulrich. It is not wholly clear why the Oswego, which appears to be the stratigraphic equivalent of the lower Shawangunk, should be placed beneath it in the geologic time scale.

As there is a marked unconformity above the Martinsburg, and as the first fossils found above this stratigraphic break are distinctly younger than Ordovician, the Shawangunk conglomerate in Northampton County is tentatively referred to the Silurian period.

QUATERNARY SYSTEM

General Aspects

Although this report deals primarily with the slate, the surface cover that in many places conceals the bed rock cannot be wholly ig-

[48]Lesley, J. P., A summary description of the geology of Pennsylvania: Pennsylvania Second Geol. Survey, vol. I, pp. 674-5, 1892.

[49]Lewis, J. V., and Kummel, H. B., The geology of New Jersey: New Jersey Geol. Survey, Bull. 14, p. 49, 1915.

[50]Grabau, A. W., Physical and faunal evolution of North America during Ordovicic, Siluric and early Devonic time: Jour. of Geol., vol. 17, pp. 235-237, 1909.

[51]Schuchert, Charles, Paleogeography of North America: Geol. Soc. Am., Bull., vol. 20, p. 539, 1910. Silurian formations of southeastern New York, New Jersey, and Pennsylvania: Geol. Soc. Am. Bull., Vol. XXVII, pp. 530-554, 1926.

[52]Grabau, A. W., The Medina and Schawangunk problems in Pennsylvania: Science, N. S., vol. XXX, p. 415, 1909.

nored. When this is studied in detail it is found to consist largely of unconsolidated boulders, gravel, sand, and clay, partly indiscriminately mixed, partly laid down in definite beds. In the former case sandy clay or clay with but rare sand grains has subangular boulders scattered through it. These vary in size up to as much as three feet in diameter. They do not occupy any uniform position in the finer matrix, occurring neither as a bottom layer, nor as a definite bed interstratified with the less coarse material. The boulders are not angular, but have smooth, flat surfaces, similar in proportion to the facets on a cut gem; the edges, moreover, are bevelled. It is not uncommon to find such a boulder with groovings, resembling chisel marks, on its surface. Such criteria show that the boulders and their matrix were laid down under the glacial ice of the great ice age. Deposits of this type are called till and make up the ground moraine.

Other deposits consist of definite layers of material,—a bed of boulders, another of sand, followed above by one of boulders, perhaps,—a sequence of deposits suggesting the Paleozoic sediments already discussed, in their assorted and bedded character, but differing notably in their lack of cementation. The boulders are round and clearly waterworn; facets and scratches are very rare. There is a notable amount of associated sand and less clay than in the ground moraine. Such deposits were in part laid down directly by ice, without the intervention of streams; they then consist largely of boulders and represent the material pushed forward by the ice front and that dropped where the glacier melted completely away. In other cases, however, the water running out from the glacial front carried some of the ice-borne boulders, sand, and clay with it, laying them down again at varying distances beyond the glacial edge. Deposits of this latter type show stratification. They are properly classed as glacial outwash, but when close to the ice edge they are so intermingled with the ice-deposited material as to be inseparable in the field; ice-borne and glacial stream material, when deposited at the ice edge and thus closely associated, are generally classed together under the head of terminal moraine.

Those boulders, sands, and clays carried far beyond the ice terminus by streams of water furnished by the melting ice are spoken of collectively as outwash. As they compose some of the terrace covers along streams they are here treated under the heading of terrace deposits.

Glacial Deposits

Earlier work.—Previous work on the geology of this region was undertaken by Lewis, Williams, and Salisbury.[53] Lewis traced the

[53]Lewis, H. C., Report on the terminal moraine in Pennsylvania and western New York: Pennsylvania Second Geol. Survey, Report Z, 1884; Williams, E. H., Notes on the southern ice limit in eastern Pennsylvania: Am. Jour. Sci. Ser. 3, vol. XLIX, pp. 174-185, 1895; Salisbury, R. D., The glacial geology of New Jersey: New Jersey Geol. Survey, 1902.

terminal moraine deposits marking the edge of the ice across Blue Mountain east of the Big Offset (Delaware Water Gap sheet), through the towns of Delabole and Factoryville and thence east to the mouth of Oughoughton Creek and Belvidere. Williams showed that glaciated boulders, clearly not waterworn, also lay some distance south of the moraine recognized by Lewis; he stressed especially the deposits made at the front of the ice in lakes that were formed because of the impounding of rivers through ice-dams. Salisbury followed the terminal moraine of Lewis eastward from Belvidere across New Jersey; his studies led him to conclude that an earlier ice-sheet, which he called the Jerseyan, laid down some of the materials recognized by Williams south of the Lewis moraine.

Ground moraine deposits.—The deposits laid down under the ice and called ground moraine, are not very conspicuous in any part of the region studied. Moreover, they pass by gradation into the material laid down at the front of the ice. A good example of ground moraine is furnished by the overburden seen at the southwestern corner of the North Bangor quarry. Here there is about 20 feet of glacial clay, with intermingled boulders. The latter measure up to three feet, but most of them are one foot or less in diameter. The boulders are scattered through the clay, with no evidence of assortment. They are not well rounded, and many are distinctly faceted; none bear scratches or grooves. Some are of Shawangunk sandstone or quartzite, some of the Silurian, Devonian, and Mississippian sandstones and shales which lie north of the crest of Blue Mountain. The matrix is clay, with a little sandy material.

Deposits of this type are common in the soft slate district. At the Columbia Bangor opening at Bangor, extensive stripping has laid bare material similar to that just described. This feature is shown in Plate IV, B. At the Jackson Bangor No. 5 and Jackson Bangor No. 7 quarries, such glacial till occurs again. An excellent exposure is seen in the Stoddard quarry, about one mile east of Wind Gap. Here twelve feet of till lie above the slate. The morainic material consists of boulders a foot or less in diameter, set in a matrix of clay. The boulders are quartzite and conglomerate for the most part, but one of red, fine-grained, micaceous sandstone was also seen. By far the greater part are faceted and subangular, although no striae could be recognized.

Again, in the railway cut about one mile northwest of Johnsonville (Delaware Water Gap sheet), a depth of fifteen feet of unstratified clay bearing scattered glacial boulders is to be seen.

In general the thickness of this material is less than fifteen feet, but there are notable exceptions and irregular variations. Thus at the Diamond, Albion Vein, and Doney quarries the overburden is negligible, the slate showing at the surface, while at the Albion Bangor

quarry the ground moraine is about fifty feet thick. The impression is gained that the glacial overburden is thick in the soft slate belt, but thins rapidly with its approach to the belt of land underlain by the middle, sandy member of the Martinsburg formation.

Terminal moraine.—The terminal moraine marks the position of the front of the ice sheet for an extended period, but does not necessarily indicate the southernmost limit of its advance. It is clearly defined in the region of the Delaware Water Gap sheet, but passes into the ground moraine deposits west of Pen Argyl without a definite boundary, so that no attempt was made to limit it in the Wind Gap quadrangle. Two features make it recognizable; these are the rough topography culminating ideally in an almost continuous ridge or a series of closely spaced ridges, and the rounded boulders, stratified sand, and generally assorted character of the deposits that make up such ridges.

As the ice front retreated and advanced irregularly, it may be expected that the ground and terminal moraine deposits are intermingled in many localities. No attempt was made, therefore, to separate these two types of ice work, but a line was drawn marking what is regarded as the outer edge of the terminal moraine.

The development of the terminal moraine is well shown on the main highway between Bangor and Pen Argyl, about one mile west of Bangor. Here the rough topography is conspicuous; numerous hills rise thirty feet above the general level of the country, with depressions. In the highway, these knobs are seen to consist of sand and of well rounded boulders up to two feet in diameter. At Blake's farm, about half a mile west of the Bangor post office, a shaft passed through about 50 feet of sand and gravel.

Along the valley of Waltz Creek the outwash material—that carried out from the ice front—and terminal moraine deposits are mingled. About half a mile northwest of Ackermanville several sand pits have been opened in such deposits.

In one of these are eight feet of well-stratified sand, covered with three inches of cobbles and slate chips which are set in clay. The sand is well assorted into beds of alternately finer, clayey and coarser, purer sand. Some is current-rippled, the more gently inclined surfaces of the ripples being toward the northeast and the crests elongated northwesterly. Elsewhere cross-bedding is seen with predominantly southward dips.

About 500 feet west of this pit is another. Here the uppermost two feet consist of rounded boulders of which only a few still show facets; these are set in sand and clay matrix. Below this is the following sequence, in descending order:

	Inches
Pure sand	4
Gravel	3
Pure sand	5
Coarse gravel	4
Coarse sand	3
Coarse gravel	8

No well-defined cross-bedding could be seen, but separate layers dip 12-25° S.

A third pit, 400 feet N. 60° E. of the last, shows many boulders still largely faceted. It is thus clear that these materials all represent deposits of mixed terminal moraine and outwash.

About a quarter of a mile south of Ackermanville the terminal moraine deposits are conspicuous along the tracks of the Northampton electric railroad. Here an erratic boulder measuring 8 by 20 by 20 feet lies in the field west of the road. This is seen in Figure Plate V, A. Several little kames were laid open when the road was built.[54]

As the terminal moraine is crossed by post-glacial streams, its deposits have been carried down the valleys, so that large glacial boulders now form a "float" beyond the present limits of the moraine.

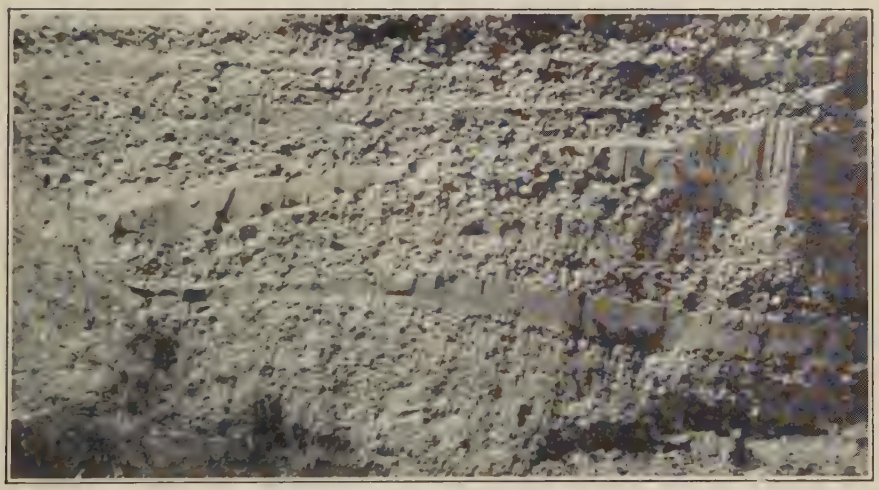
West of Pen Argyl the deposits made at the edge of the ice are poorly defined. Lewis traced them northward across Blue Mountain east of the Big Offset. This is almost certainly too far east, for the terminal moraine south of Blue Mountain extends as far west as Delabole. Much of the loose rocks in the soft slate belt west of Wind Gap and south of Blue Mountain suggest morainic material rather than talus or stream deposits by the large size and faintly faceted character.

In the area of the clearly-marked terminal moraine, the glacial cover is heavy and much overburden must be removed to reach the slate.

Extra-morainic drift.—South and west of the terminal moraine in the Delaware Water Gap region and well south of any deposits that might be regarded as marking the southern limit of the ice advance in the Wind Gap quadrangle, is a thin veneer consisting of glacial and glacio-fluviatile drift, sporadic in occurrence. This consists of faceted boulders of the sandy member of the Martinsburg and more rarely of the Shawangunk conglomerate. Only occasionally do such boulders

[54]Lewis, H. C., Report on the terminal moraine in Pennsylvania and western New York: Pennsylvania Second Geol. Survey, Report Z, Plate 3, p. 34, 1884.

A. Glacial erratic, 20 feet square, a quarter of a mile south of Ackermanville along the electric railway.



B. Gravel pit at Hutchinson's garage, Martins Creek; north face of cut. Shows westward cross-bedding in lenses of sand between gravel deposits.

C. Rough topography of outwash and terrace deposits in the valley of Jacoby Creek, west of Portland. The church to the right is on an old terrace. Lesser terraces can be seen to the left.

show striae. Many are covered with yellowish-brown iron oxide; their surface is smooth and glossy. Sandy clay serves as the matrix.

Thick exposures of this material are not common. Generally the presence of such glacial till is indicated only by the occasional boulders in the fields. But on the east bank of Little Bushkill Creek and south of the road leading east from Werkheiser, is a small quarry in which the slate is covered with an overburden of 15 feet of fine clay; this is the matrix for poorly assorted gravel and cobbles ranging in size up to eight inches. A few cobbles are striated; many are faceted. Apparently this deposit represents till reworked by running water.

Such deposits have been interpreted by Salisbury[55] as representing an earlier glacial advance, called the Jerseyan glaciation. This interpretation may be tentatively accepted.

Generally the glacial deposits are not as conspicuous on the higher hills as in the lower topography. The impression is given, also, that there is more till lodged on the southern slopes of the hills than on their north sides, as might be expected with the deposits of a southward moving glacier.

Non-Glacial Deposits

Terrace deposits.—Terrace deposits, partly laid down by glacial streams, partly very recent in origin, are common in the region. They are most conspicuous along Delaware River and in the valley of Jacoby Creek. Thus, a very well developed terrace lies about 200 feet above present water level on the east side of Delaware River, south of Browning. The material covering this terrace consists of boulders, mixed with sand. Such deposits apparently extend down to the present level of the Delaware, and on the western side of the valley, south of Slateford, the sapping of the bank has exposed a thickness of at least 60 feet of gravel and sand. Another terrace about 60 feet above river level is seen on both sides of the Delaware one mile south of Portland. These and lower terraces have been ascribed by Salisbury to the work of glacial and post-glacial streams.[56]

Farther down the valley of the Delaware similar deposits are found, partly laid down by streams flowing out from the glacial front. The valley of Jacoby Creek is filled with such material, which is well shown west of Portland, (Plate V, C). At Hutchinson's garage in the town of Martins Creek 25 feet of stratified sand and gravel are exposed; the boulders range in size up to 9 inches. Northward-inclined cross-

[55]Salisbury, R. D., Surface geology: New Jersey Geol. Survey, Ann. Report for 1893, pp. 73-123, 1894; Chamberlin, T. C., and Salisbury, R. D., Geology, vol. III, p. 384, 1907.

[56]Salisbury, R. D., The glacial geology of New Jersey: New Jersey Geol. Survey, pp. 285-313, 1902.

bedding was seen. This deposit is clearly stream laid (See Plate V, B).

Talus.—The southern escarpment of Blue Mountain owes its relatively gentle slope to the rock fragments which have accumulated at the foot of the cliff of Shawangunk conglomerate. These have been somewhat rolled by water and so are locally rounded, but most of them are subangular. They are most conspicuous west of Pen Argyl. Though also seen to the east between Pen Argyl and Delaware River, the fragments are so intimately mingled with glacial and terrace deposits that only those actually on the escarpment slope or still retaining their angular form can be clearly recognized as talus material.

DETAILED STRUCTURE

FOLDING

Definitions.—It is customary, for convenience in description, to speak of the line of intersection of an inclined plane surface with a theoretical horizontal plane as the strike. The maximum vertical angle made by this horizontal plane with the inclined surface in question is the dip of the plane. When the strike and dip of a plane are thus given, its attitude is fully defined. The attitudes of bedding, cleavage, joints, and faults, being approximately plane surfaces for short distances, can be described in the same manner. Commonly the strike and dip of any such natural plane are given in figures like these, —strike N.60°E., dip 20°S. This means that the trace of the plane on the horizontal surface bears N.60°E. in azimuth, and the maximum angle between the ideal horizontal plane and the surface face described is 20°; the S. indicates that the surface inclines downward toward the south.

When beds are folded they commonly assume the form of parallel waves, in this case the troughs are spoken of as synclines, the crests as anticlines. The flanks of such folds are designated the limbs.

When the beds appear to dip in one direction only, and there is no evidence of a compensating oppositely directed inclination, the structure is said to be a monocline.

It frequently happens that the troughs and crests of the folds are not strictly parallel with the horizontal plane to which the beds are referred, but inclined upward in one direction. This situation can be likened to the appearance of a horse trough, tilted so that the water will flow down the length of the trough. Such tilted synclines and anticlines are said to pitch in a specified direction, that toward which the length is inclined downward.

The plane separating the two limbs of a fold, so as to make equal angles with each limb, is called the axial plane or plane of the fold,

Its intersection with the horizontal plane of reference is the axis of the fold.

Interpretation of folded beds.—In strata like those of the Martinsburg, where each bed is much like the next, fossils are lacking, cross-bedding is inconspicuous, and ripple marks are rarely seen, it is difficult to recognize top and bottom of beds on the basis of sedimentary features. This condition makes it hard to tell from the usually small outcrops whether or not beds are overturned, that is, having the older strata above, the younger below. Nevertheless, many quarries show folds in which the beds of one limb are clearly inverted: it is obvious therefore, that some method must be used for distinguishing, for example, between beds dipping southward and lying on the north limb of symmetrical syncline and beds dipping southward but on the south limb of a northward recumbent syncline. The clue to such a distinction is furnished by the cleavage.

It has long been known that the cleavage in slate tends to parallel the axial planes of the folds and thus to bisect the angle formed by the two limbs. Where the beds dip southward more steeply than the cleavage they must be overturned and on the southerly synclinal limb; if the cleavage has the steeper dip, the beds are on the northern limb. This relationship is shown in Figure 7. Further, if, on

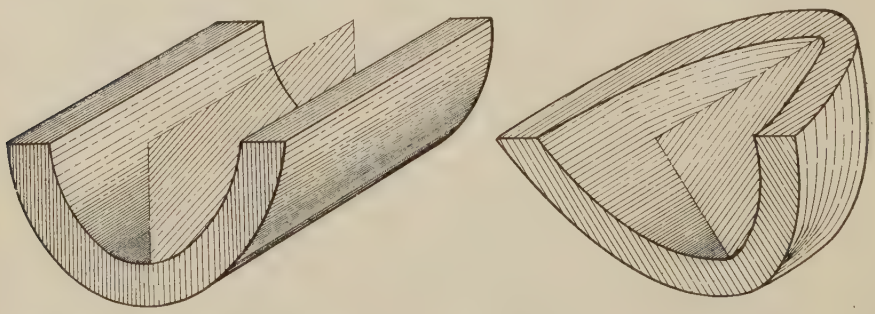


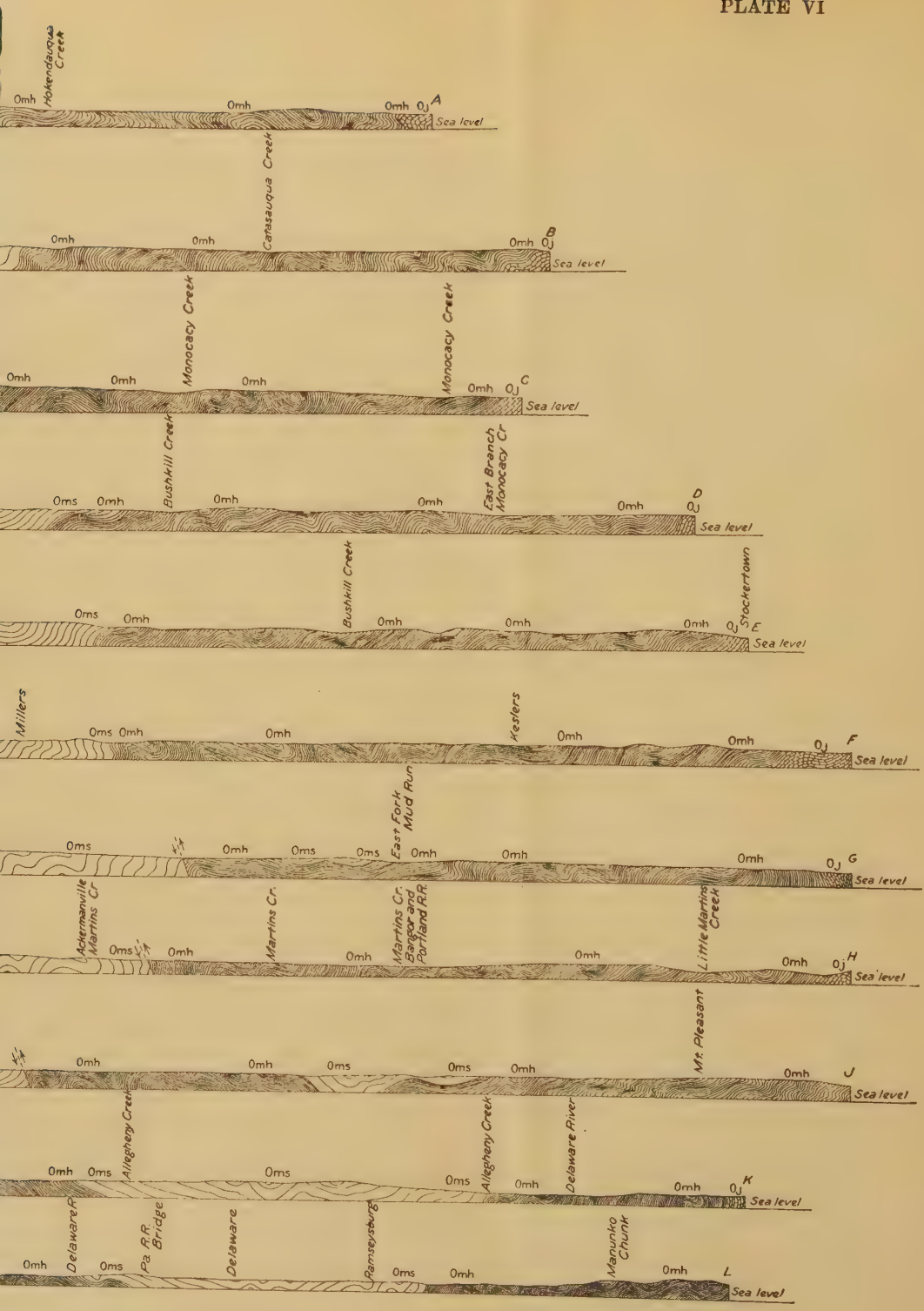
Figure 7. Ideal relations between cleavage, axial plane, and bedding in symmetrical fold and fold overturned to the left. Traces of cleavage planes bisecting both folds are indicated.

the horizontal surface the cleavage trace is parallel with the bedding trace, the axis of the fold is horizontal. But where the cleavage and bedding traces intersect, it is obvious that the fold pitches, and in such cases the relation between strike and dip of bedding and cleavage planes furnishes the clue to the direction of the pitch. These facts are illustrated by Figure 7.

Summary of folding.—In the order of increasingly careful and detailed scrutiny, three impressions of the folding in this region are conveyed to the observer. First, he notes a generally northerly dip.

STRUCTURE SECTIONS

Letters refer to corresponding letters



ACROSS SLATE DISTRICT.

on map, Plate II. Scale as on Plate II.

of all the strata, so that progressively younger beds are encountered in a northward traverse; the general strike of this huge monocline is approximately N.60°E. This generalization applies to all the formation of the region.

A further study reveals on this large monocline numerous folds, in places with limbs closely appressed and almost (but nowhere quite) isoclinal. These small folds are rarely symmetrical and generally have suffered northward overturning. The south limbs of anticlines dip steeply south in but few instances and more commonly are horizontal or nearly so, or even gently inclined northward; the north limbs approach the vertical or have been overturned to such an extent that they actually dip southward at high angles. In general these extreme overturns are limited to the slate, but in places they are to be seen in the underlying limestones.

The structure strongly suggests that described by Dale in the Green Mountains of Vermont,[57] except that the strikes in Pennsylvania are east-northeast, whereas in Vermont they are more nearly due north.

Third, almost anywhere, upon close examination, it can be demonstrated that these smaller folds pitch in one or both directions along the strike. This last fact is what might be expected of the clay of the Martinsburg formation which, upon the application of sufficient pressure, must have flowed and adjusted itself internally. In such a medium portions under least pressure are the loci toward which is forced the excess matter from regions of greater stress, until internal stresses have been accumulated to counterbalance the external forces. Cross sections of the structure are shown in Plate VI.

Types of folds.—The type of fold appears to be determined by the thickness and competency of the strata affected. In the hard slate member, where the individual beds are thin and were apparently quite plastic when first compressed, the folds are acute and very sharply pointed; the opening angle between two limbs of a fold may be as little as 9°, as is seen in an exposure along the Lehigh Valley Railroad about one mile northwest of Treichlers Station in the Slatington quadrangle. In the middle, sandy member of the Martinsburg formation, where massive calcareous sandstones exist, the folds, though not generally well shown, are never observed to be very tightly compressed. In the soft slate member, on the other hand, especially in the Bangor beds, which apparently met the compressive resistance of the more massive sandy member to the south, the folds are closer. Yet even here no fold measured in a plane at right angles to the strike shows an opening angle of less than 42°, the "tightest" folds measured being the Old Bangor syncline and the Peerless syncline, as seen in the Old Bangor and New Peerless quarries.

[57]Dale, T. N., Structural details in the Green Mountain region and in eastern New York: U. S. Geol. Survey, Bull. 195, pp. 9-20, 1902.

One of the striking features of the folds in the slate is the absence of isoclines. The picture of isoclinal folding as a prevalent feature in the slate is not borne out by the facts observed in this region. When the folds are not pitching, however, it is clear that the corresponding limbs of two adjacent folds are roughly parallel, though no limb is parallel with the opposite side of the fold of which it is a part.

Pitch of folds.—Almost all folds have a gentle pitch northeastward or southwestward. It is probably true, in fact, that such pitches are the rule and that exceptions are very, very rare. However, the evidences of such pitches are usually indirect and often not conclusive. In the large outlier of middle Martinsburg extending from Delaware, N. J., on the eastern edge of the mapped area almost to Nazareth Junction there is every suggestion, in the westward thinning of the areal exposure of the sandstone, that an eastward pitch exists; however, little verification for this conclusion is furnished by actual bedding dips.

The evidence is clearer in the case of a fold at West Bangor. Here the Bangor Superior quarry shows strikes diverging from the general strikes of the region, and an exact correlation of the beds enables the reconstruction of the westward-pitching syncline near the axis of which this quarry is located.

At the Mountain View, Shimer, and Consolidated No. 2 quarries the strike of the beds which appear in the Consolidated No. 1—Star quarry and openings farther west turns northward and even northwestward, until it is actually at right angles to the bedding strike to the west.

Where the folds have axial planes that are horizontal or nearly so, the equivalent of pitch in a fold is a northward swing of the trough of synclines or crest of anticlines. To express this fact in another way, the concept of the axial line is here developed. The term "axial line" is applied to the intersection of the axial plane with any single bed. With this definition in mind, the appearance of a typical recumbent fold in the slate may be described by saying that a vertical projection of the axial line of such a fold upon the horizontal plane would be a curved line. Hence on vertical planes, such as quarry walls, drawn through the strike of the axial planes of such folds the traces of beds appear as ellipses, generally flat.

In addition to these complications, there is a suggestion in the relations of beds at the Albion and Albion Vein quarries and at the Jackson Bangor No. 5 and Jackson Bangor No. 6 quarries of a vertical warping of the approximately horizontal axial planes. This suggestion cannot be verified with accurate measurement, however.

There are thus two complications in the structure of the recumbent folds of the slate:

1.—The axial lines are not straight but curved.
2.—The axial planes are warped surfaces.

Thinning and thickening of beds by folding.—Many beds show thinning and thickening by folding. It is generally true that the incompetent layers are thicker on troughs and crests of wave-like folds, while they are greatly thinned on the limbs.

This principle is well illustrated by a view of the northeast wall of the Old Bangor quarry, (see Plate XXIII B), which shows the great thickening of the beds in the trough of the Old Bangor syncline. It is equally well shown in the New Peerless (Bangor Vein) quarry and somewhat less strikingly in the North Bangor and Bangor Union openings. The same fact is brought out quantitatively by a study of the detailed sequence measurements in the Columbia Bangor and Bangor Central quarries.

Comparison of thickness of beds in several Bangor quarries.

Name of quarry	Name of bed	Dip of bed	Thickness Inches
Old Bangor	Middle big bed	20°S.	42
Columbia Bangor		44°N.	122
Old Bangor	Gray bed	20°S.	34
Columbia Bangor		44°N.	132
Bangor Central	Uncle Sam bed	4°N.	19
Columbia Bangor		44°N.	124
Jackson Bangor No. 6	1st Five-Foot bed	10°N.	73
Albion		37°N.	43
Jackson Bangor No. 6	Hard big bed	10°N.	143
Albion		37°N.	113
Parsons	Genuine big bed (Diamond "run")	73°S.	82
New Diamond		64°S.	52

All of the comparisons here presented, with the exception of that between thickness in the Jackson Bangor No. 6 and Albion quarries, are illustrative of the principle enunciated above,—a principle long accepted where rock is deformed as a partially plastic mass ("zone of flow" of Van Hise). In the exception noted, there is a strong suggestion that the north (or vertically lower) limbs of synclines generally suffer more thickening than the south limbs—at least as far as observations go. A similar case, which illustrates progressive thickening as the north limb of the syncline is approached is furnished by accurate measurements made at several levels in the northeastern wall of the Albion quarry.

Comparison of thickness of Gray bed in Albion quarry.

Depth below surface (feet)	Cleavage dip	Bedding dip	Thickness (inches)
0	5°N.	27 °S.	54
85	6°N.	28.5°S.	80
120	5°S.	35 °S.	79
275	35°S.	19 °N.	112
285	26°S.	9 °N.	113

It is thus seen that as the beds approach the axis from the south limb of the syncline they thicken and apparently retain on the north limb much of the thickness acquired at the axis.

The extreme of the axial thickening of beds is to be looked for in places where the folding is very flat and where there is a single dominant fold—as in the Old Bangor syncline,—rather than a series of folds lying one above the other and with axial planes about parallel, as in the Albion Vein quarry. This might be expected, as the actual length of material available for packing at the synclinal or anticlinal trough or ridge is less when the beds are thrown into repeated close folds, the distance from trough to crest being less.

Method of restoring folds.—The vertical depth of exposure in any given place in the region studied is so slight that a general method had to be devised for interpreting structures and projecting dips. Three principles were applied. The first is that in general, cleavage approximately bisects the opening angle between the opposite limbs of a fold; or, to put it differently, the cleavage planes are parallel to the axial planes of folds. The second is a corollary of the first, namely that a dip observed at the surface is duplicated in depth at the intersection of each successive bed with the cleavage plane seen at the surface. The third principle is based on empirical observation: in the upper and lower members of the Martinsburg, and probably in the middle, sandy member as well, the normal structure is a recumbent or nearly recumbent folding overturned to the north.

These methods are illustrated by Figure 8.

Shortening by folding.—Numerous estimates of the crustal shortening of folded areas have been made in the past.[58] Claypole estimated the transverse shortening of the Pennsylvania Appalachians to be 46 miles, 35 miles in 100, or a ratio of 1:1.53. Chamberlin[59] estimates the original transverse width of the Appalachian strata from Tyrone in Blair County, Pennsylvania, to Harrisburg to be 81 miles, as against the 66 miles of present width. He concluded that a "rough guess" would give a crustal shortening within the Martinsburg shales, such that the ratio of final to original horizontal length can be expressed by

[58]For a summary of some such estimates by Dutton, Heim, LeConte, Claypole, and McConnell, see Chamberlin, T. C., Estimates and causes of crustal shortening: Jour. Geol., vol. VI, pp. 10-12, 1898.

[59]Chamberlin, R. T., The Appalachian folds of central Pennsylvania: Jour. Geol., vol. XVIII, pp. 230-237, 1910.

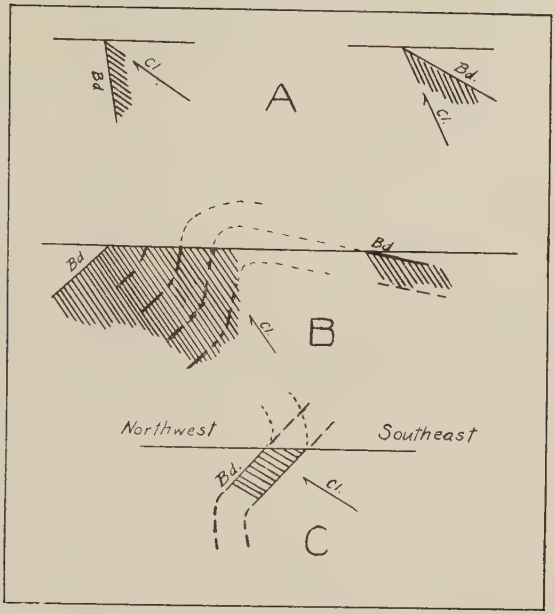


Figure 8. To illustrate methods of restoring folds from cleavage and bedding relations. A. Left, beds overturned to left; right, beds normal. B. Restoration of dip of beds with depth. C. Determination of true structure; dotted lines incorrect, dashed lines correct interpretation.

the ratio 1:2. Peck[60] finds the crustal shortening very much greater, the ratio of final to original length being 1:6. Actual measurements of a section given by Peck 4.16 miles long,[61] gave an original length of 8.82 miles of strata, so that the crustal shortening is in the ratio of 1:2; the measurements were made in the rather massive Cambro-Ordovician dolomite.

It seems probable that the shortening in slate would be greater than that in the more competent strata. Two estimates of shortening in short sections of the hard slate in the railroad cuts along Lehigh River between Siegfried and Rockdale in the Slatington quadrangle gave approximately equal results: in one case 30.5 feet of beds were shortened to 25 feet measured on the horizontal; in another case 142 inches were reduced to 110 inches. The ratios obtained were thus 1: 1.22 and 1: 1.29. A section through the Old Bangor and Bangor Excelsior quarries gave a shortening of 1: 1.13, the actual length of the beds measured being 2125 feet. Very probably the shortening near Pen Argyl would be greater. A far less accurate measurement along the section L-L' (see structure sections) gives a shortening of 4.55 miles of actual length of the middle, sandy member of the Martins-

[60]Peck, F. B., Preliminary report on the talc and serpentine of Northampton County and the Portland cement materials of the Lehigh district: Pennsylvania Top. & Geol. Survey, Report No. 5, p. 39 1911.

[61]Peck, F. B., Geology of the cement belt in Lehigh and Northampton Counties, Pa., etc.: Econ. Geol., vol. III, p. 54, 1908.

burg into 4.1 miles of outcrop; the shortening ratio is thus 1: 1.1. A similar case along the section J-J' gives a shortening of 2.5 miles of strata into 2.07 of outcrop, or a ratio of about 1:1.21.

Taking all these results into consideration it appears that the ratio between the present and original lengths of the Martinsburg formation, omitting thrust faults, is about 1:1.20.

Direction of pressure.—The question naturally arises as to the direction from which the pressure producing the observed folding came. The question was long ago faced by Willis[62] and has lately been reviewed in great detail by Keith[63]. Both these writers conclude that the deforming force or forces in the Appalachian Mountains came from the southeast and moved northwesterly. Briefly stated, the field evidence on which this conclusion rests is three-fold:

1. In a northwest-southeast section across the Appalachians, the southeasterly rocks are more severely folded and more highly metamorphosed than those to the northwest.
2. Folds generally show overturning toward the northwest, or where not overturned the anticlines exhibit steep northwest and gently dipping southeast flanks.
3. Numerous thrust faults, formed either during the movement that produced the folds or at least by a similarly directed thrust, are found: their planes dip more or less gently toward the southeast.

In the course of this work, the second of these facts was repeatedly corroborated. It is true that in experimental deformation, such as that produced by Willis and later elaborated by R. T. Chamberlin and others, the folds sometimes show overturning toward the source of movement, instead of away from it, but this is only after such folds have been sufficiently uplifted to be beyond the reach of the direct thrust, when their inertia keeps them from moving forward over the mass below. The stages by which this high-inertia type of recumbent folding, with anticlinal axial planes dipping away from the applied pressure, is reached are well illustrated in Willis's experiments[64]. Only when some special conditions, such as previous irregularities in dip, are introduced can the axial planes of the folds be made to dip away from the moving force.

In this discussion it is clearly understood that opposition to this moving force is needed to produce pressure. To say that thrust faults or structural features bear a certain relation toward the "pressure" is dynamically incorrect. It is true, however, that that side of a mass at which a moving force is applied suffers deformation first and with

[62]Willis, Bailey, The mechanics of Appalachian structure: U. S. Geol. Survey, 13th Ann. Rept. part II, p. 281, 1893.

[63]Keith, Arthur, Outlines of Appalachian structure: Geol. Soc. Am., Bull., vol. 34, p. 336 et seq., 1923.

[64]Willis, Bailey: Op. cit., Plates LXXXIII, LXXXV, LXXXVI, LXXXVII, etc.

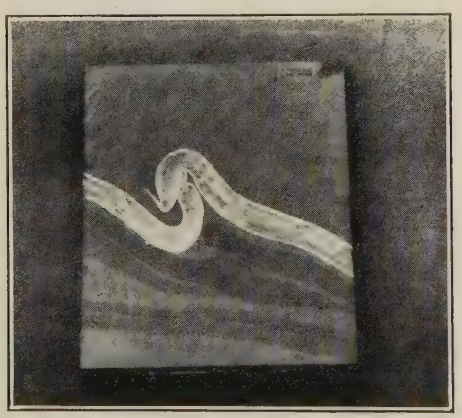
more intensity, than the other side, which remains unmoved and serves mainly as a buttress. Pressures are equal at the two ends of the compressed mass, but inertia and friction are not.

One more piece of evidence is cited to show that the moving forces deforming the slate came from the southeast. Careful measurements of thickness show that beds are thicker on the north limbs of synclines. An example is furnished by the Gray bed of the Pen Argyl beds. As measured in the Albion quarry this has a thickness of 80 inches on the south limb of the syncline in that quarry, but thickens to 112 inches on the northern limb of the structure, only 200 feet lower down. Such a thickening on the northern limbs of synclines is what would be expected if the moving force came from the south.

Pre-cleavage folds.—A few folds were seen that must have antedated the development of the slaty cleavage. Their characteristics are their small size, and the fact that their axial planes are steeply inclined to the plane of the slaty cleavage. An example is afforded by a small fold obtained from the mill of the West Bangor quarry. (See Plate VII).

Figure 9. Drawing of thrust fault in photograph below.

PLATE VII



Photograph of small pre-sericitization thrust fault in soft slate; from mill of West Bangor quarry; width of block, 12 inches.

CLEAVAGE

Terms defined.—The term cleavage has been applied to three different structures in slate. It has been used to designate parting along numerous, close-spaced, and parallel planes that bear no relation to bedding; this is true "cleavage" and the use of the term should be limited to this feature. Cleavage has also been applied to a tendency to part along small joint-like openings, more closely spaced than joints, but less so than true cleavage planes, and generally inclined to the cleavage; this, following Dale, may be called "false cleavage". A third set of fracture planes of which no trace is visible to the naked eye until the slate is actually broken and which is generally at right angles to the true cleavage, is the "grain", "sculp", or "scallop" of quarrymen. In this paper the terms cleavage, false cleavage, and grain are used in the senses indicated above (See Plate XI, B).

Origin of cleavage.—The origin of cleavage is attributed to recrystallization of the minerals during the metamorphism of shale to slate. Very probably the shale is already supplied with some flat-faced minerals, such as sericite, but during the metaphorism, its content in these is still further augmented. The tabular or flat crystals developed are oriented so that their flat surfaces are parallel throughout considerable bodies of slate. The slate, when split, breaks most easily along these surfaces.

Relation of cleavage to stress.—The question of the position of the flat surface with respect to the direction of the applied pressure has given rise to repeated experiments and controversies. A condensed summary of the various views in regard to this problem is given by Leith.[65]

Prevailing strike and dip of cleavage.—One outstanding feature of the cleavage in this region is the constant strike of the cleavage (about N. 60° E., parallel with most of the fold axes).

It is noteworthy that cleavage generally has a lower angle of dip than bedding. As the cleavage planes approximately parallel the fold axes, the foregoing statement emphasizes the recumbent nature of the folds. (See Fig. 7, 8). In a few localities it appears that cleavage and bedding are parallel for short distances.

Curvature of cleavage.—The cleavage planes are not uncommonly curved, the planes sometimes assuming an S-shape, apparently due to added compression after cleavage formation. This type of curved cleavage is especially noticeable near bedding slip faults (See p. 65).

In addition to the marked cleavage curvature just referred to, there is a tendency, where cleavage planes cross sandy beds, for them to curve slightly. This type of curvature is not induced by deformation after the development of cleavage, but is due merely to the higher

[65]Leith, C. K., Rock cleavage: U. S. Geol. Survey Bull. No. 239, 1905.

angle between cleavages and bedding, in sandy beds where mica and chlorite, the cleavage producing minerals, are less well developed than in the typical slate. There is a strong suggestion in such a feature, of a relation between plasticity and cleavage.

In a few quarries the cleavage shows a gentle curvature or changes slightly in dip from top to bottom of the quarry. This is especially clear in the Albion quarry, in which each level is developed on a very gentle curve, so that the cleavage forming its floor actually dips northward near the northern border.

Relation between cleavage and axial planes of folds.—In the area studied, there is no evidence of inclination of cleavage to the axial planes of folds. So far as observed the cleavage planes and the axial planes of all folds are parallel, so that the fan-shaped effect, mentioned by various writers[66] in which the cleavage converges toward the axis of anticlines, must be regarded as exceptional in this region at least.

FALSE CLEAVAGE

Description.—Not uncommonly, especially in thin beds of slate between layers of the sandstone of the middle member, a cleavage surface shows fine fissures, frequently short and seldom conspicuous, forming planes more or less at right angles to the cleavage. When such slate is struck with the hammer, it cleaves and at the same time splinters into slender pencils, breaking along the fissures mentioned. These fissures are the "fracture cleavage" of Van Hise, the "false cleavage" of Leith, or "slip cleavage" of Dale.

Seen under the microscope the false cleavage planes are seen to be due to extreme plication of true cleavage planes. As they approach a zone of false cleavage, the shreds of muscovite and chlorite show some curvature, and, instead of showing as straight lines (the condition in normal slate cut at right angles to the cleavage plane), become undulating. The orientation of these minerals in the undulatory strands is well marked because one limb of any single tiny undulation is dark under crossed nicols, while the other is relatively light. As the folding of the cleavage strands becomes progressively more intense, the strands tear apart along a line more or less at right angles to their length and open, joint-like fracture develops; this latter is true fracture cleavage ("false cleavage"), the flexings being incipient stages of fracture cleavage, to which Van Hise's term fissility might be applied. An illustration is furnished by Figure 10.

It is significant that false cleavage of this type is not observed in the really competent beds of sandy material, nor is it seen where the sequence through great thickness consists wholly of slate. It was, in fact, best developed in thin beds of slate lying between thick sandy

[66]Dale, T. N., Slate in the United States: U. S. Geol. Survey Bull. 586, p. 35, 1914.

layers, and in these cases the bedding planes on either side of the strata bearing this type of cleavage are mullioned, or striated down the dip, or show wrinkling of their surfaces,—all suggestive of movement along bedding planes.

So far as noted there is in any given locality only one set of false cleavage planes. These generally strike N.60°E., and thus parallel the true or slaty cleavage in strike, but dip well-nigh vertically. Indeed, when cleavage is actually folded the planes of false cleavage are noted to parallel in strike the folded axes of the true cleavage.

Origin.—Leith and Dale are in virtual agreement as to the immediate cause of the false cleavage. Dale[67] says that false cleavage is indicated by a system of lines on the surface of the slate which "are due to a secondary * * * cleavage, a slip cleavage developed upon

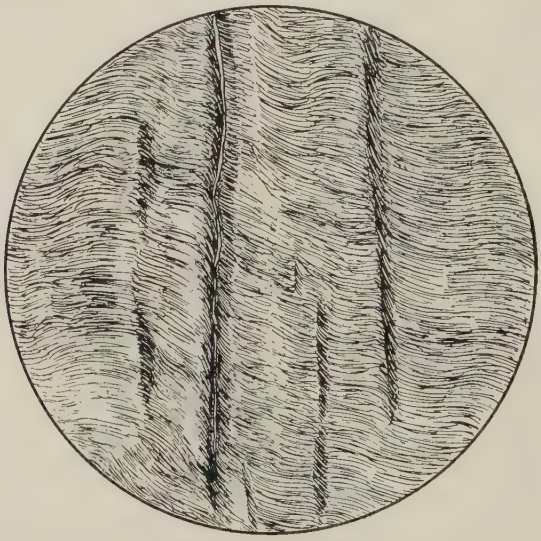


Figure 10. False cleavage and incipient false cleavage in slate. The vertical open space is a false cleavage plane. True cleavage crosses from left to right. Enlarged 66 diameters.

primary slaty cleavage. They consist simply of very minute plications which usually result in microscopic slippages or faults along which the slate easily breaks." It is not clear from this description that the development of false cleavage is thought to be of much later age than the true (slaty) cleavage, rather than merely a further extension of a continuous process effected by the same dynamic metamorphism that produced the true cleavage.

Leith cites, as a type of fracture cleavage, "fault-slip" cleavage and describes a case of the latter in which "the layers of rocks have been minutely crenulated, and the folds have passed into minute

[67]Dale, T. N., Op. cit., p. 37.

fault slips."[68] He also says, [69] "The so-called 'false cleavage' is usually the result of closely spaced, parallel, overthrust folds grading into minute faults, crossing a previously developed flow cleavage." There is thus a definite recognition by Leith of a later folding of true (slaty) cleavage to develop the false cleavage here discussed.

This latter view is substantiated by all observations in the slate. If the formation of sigmoidally flexed slaty cleavage is to be assigned to a distinct movement, later than the dynamic metamorphism that altered shale into the slate, then the development of false cleavage, which is a perfect microscopic replica of the large scale sigmoid flexures in the slaty cleavage, is to be attributed to the same later stress-period. The presence of fracture cleavage superimposed on slaty cleavage is thus clear evidence for two periods of folding.

Distribution.—Some of the localities where false cleavage is best seen may here be mentioned. It is well shown in the railway cut east of Delaware River 3,000 feet north of the village of Delaware, N. J., and 200 feet north of the bridge across the Delaware River. It may also be seen about half a mile west of Cherry Fort (Treichlers) station on the Lehigh Valley Railroad, in the Slatington quadrangle.

GRAIN

Description.—When slate is broken in any of the quarries studied, it parts along the cleavage and also along less well defined fractures of about vertical dip. Typically four sides of the block to be quarried are thus formed by easy splitting,—the top and bottom by cleavage planes and the two of the remaining four sides by the planes of fracture mentioned (Figure 11). These planes of fracture define the "grain", "sculp", or "scallop" (See also Plate XI, B, p. 74).

Such fractures differ strikingly from typical false cleavage in two

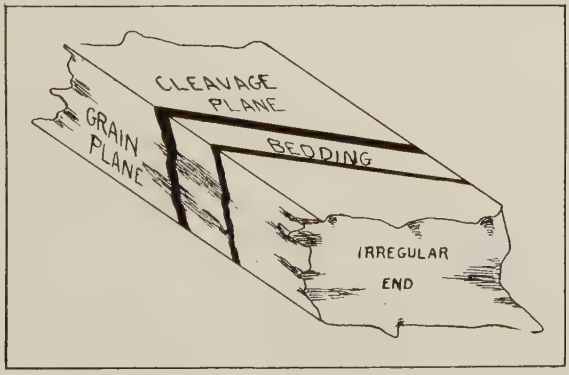


Figure 11. Structural features in slate, as quarried.

[68]Op. cit., p. 133.
[69]Idem., p. 120.

ways, one of which is that they are not sharply defined and virtually unwarped planes, but are more or less curved and irregular surfaces, which can be treated as planes only when generalized. Yet when broadly viewed the grain surfaces present so remarkable a constancy in direction and dip that they must clearly be regarded as a definite structural feature.

The other outstanding difference between grain and false cleavage in the slate lies in their differing orientation with regard to the dominant axes of the folds. False cleavage is generally approximately parallel in strike with the fold axes. Grain, on the other hand, commonly strikes at right angles to these axes and to the cleavage.

Leith does not distinguish between grain and false cleavage as here used. Dale, on the other hand, describes grain as showing itself "in a more or less obscure striation of the cleavage surface in a direction nearly parallel to the cleavage dip."[70]

Origin.—The explanation of grain has been attempted by early experimenters, including Daubree, Renard, and others, whose work has more recently been summarized by Dale. Both Leith[71] and Dale[72] attribute grain to the arrangement of the mineral particles in the slate. They are of the opinion that the grain direction is determined by the long dimensions of the chlorite and mica flakes. In thin sections Dale notes a parallelism between grain direction and the longest dimensions of crystals.

A study was made to see to what extent parallelism in orientation of longer diameters of minerals was observable in thin sections. A section of hard slate, cut parallel to the cleavage, showed elongation along the grain plane so striking as to be apparent at a glance. Muscovite and chlorite flakes, chloritic lenses, and even quartz granules all show a tendency to have two noticeably different dimensions, which are similarly directed throughout the section. In sections parallel to the cleavage, muscovite appears as plates in which the ratio between longer and shorter dimensions attains values as high as 15:1 although the average ratio is not over 3:1. Such ratios make it possible to distinguish clearly between the longer and shorter axes. The most striking instance of crystal arrangement is furnished by the rutile needles, which are exceedingly well-oriented, with their long axes in the grain direction.

Three carefully oriented thin sections were made of a big bed in the Albion quarry. One section was cut in the plane of the cleavage, the grain direction being indicated; of the other two, one was made in the grain plane, the other at right angles to both cleavage and grain. The slate is of a very uniform character and very little orienta-

[70] Op. cit., p. 41.
[71] Op. cit., p. 133.
[72] Op. cit., p. 41.

tion of the particles was observed in the section in the cleavage plane; even the rutile needles have their longer axes pointing in all directions. But of the two sections cut at right angles to the cleavage, that parallel to the grain shows far greater elongation of particles than that at right angles to the grain, as might be expected if the particles have their longest dimensions directed parallel with the grain.

A set of thin sections cut in similar directions, but of a "hard roll" at Pen Argyl, gave the same effect of orientation, except that no oriented rutile needles were seen in the cleavage plane. In a third set, made of slate from the New Diamond quarry, however, this effect was lacking, the sections normal to the cleavage being similar, whether in the grain plane or transverse to it, --with one notable exception: the quartz grains were distinctly elongated in sections in the grain plane, and but little so in sections normal to the grain and cleavage.

It thus appears that grain in slate is determined by parallelism of the longest dimensions of mineral particles, in much the same way that cleavage is due to the parallel orientation of the flat dimensions (basal pinacoids) of the mica and chlorite flakes which make up the greater part of the slate.

Strike and dip of grain.—If the plane of the grain be generalized from several observations so as to obviate purely local distortions, it will be found to have a very uniform strike throughout the area. Such generalized observations representing the data from 71 quarries, in some of which numerous readings were combined into a single figure, show the grain planes striking as follows:

Bearing of grain in slate quarries.

Azimuth bearing	Number of quarries
N. 70-65° W.	0
N. 65-60° W.	1
N. 60-55° W.	3
N. 55-50° W.	12
N. 50-45° W.	29
N. 45-40° W.	7
N. 40-35° W.	18
N. 35-30° W.	3
N. 30-25° W.	0

The above table does not list all grain strike readings but, because of the large number recorded, may be regarded as being truly representative of the region as a whole. The greater number of strikes are N. 45-50° W. These data are also shown graphically in Figure 12. A numerical average of the observations gives N. 43° W. as the average strike of the grain.

The grain planes are generally vertical or nearly so. No constant

regional variation in dip was observed, and no dips of less than 60° were recorded. Of the 71 quarries in which the above observations were obtained, 28 showed dips varying from the vertical: these variations did not exceed 20° in any case.

Interpretation of grain strikes.—Although not everywhere strictly correct, the statement may be made that the grain plane strikes approximately at right angles to the cleavage. French slates have been observed to show grain at right angles to cleavage in many places[73]. Dale records several of his own observations of grain in the slate belt of Vermont and New York[74]. For comparison these are listed below, together with the cleavage strike.

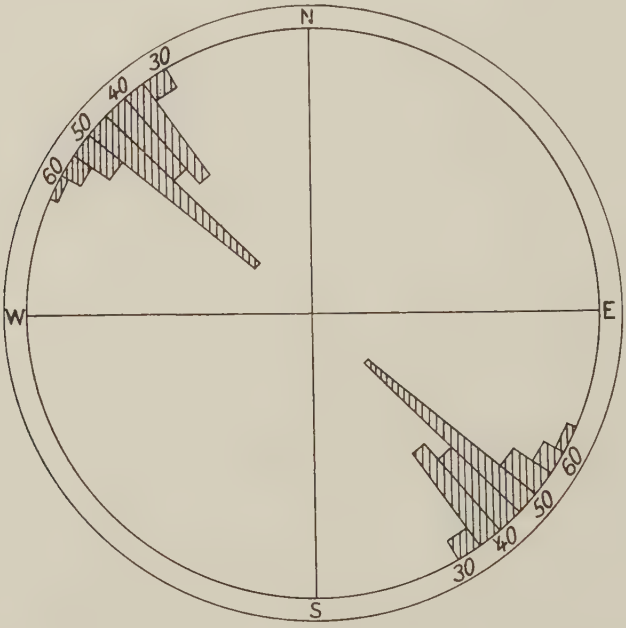


Figure 12. Azimuth chart of strike of grain as recorded in 71 quarries selected at random. The numbers indicate degrees in azimuth west of north (east of south) in bearing of grain strikes. The relative lengths of the inward extending lines show the relative numbers of observations yielding the indicated strikes.

Strike of cleavage and grain in Vermont—New York slate belt.

Cleavage strike	Grain strike	Angle between cleavage strike and grain strike
N. 5° W.	N. 45° E.	50°
N. 3° W.	N. 55° W.	52°
N. 7° E.	N. 60° W.	67°
N. 15° W.	N. 35° W.	20°

[73]Dale, T. N., Op. cit., p. 40.

[74]Dale, T. N., The slate belt of eastern New York and western Vermont: U. S. Geol. Survey, 19th Ann. Rept., pt. III, pp. 218-221, 1898.

There seems here to be little of the marked regularity in the grain strike and in the angle between grain and cleavage that are observed in the Pennsylvania quarries. This constancy in strike emphasizes the fact that Van Hise's theoretical strain ellipsoid is a three dimensional figure, referable to three planes, two of which may be regarded as paralleling the planes of maximum shear, while the third intersects these at right angles and is parallel to the grain. If, as Bucher maintains[75], the angle between the shear planes varies with the plasticity of the deformed medium, the cleavage planes may have variable dip, here more steep, there gentle, but this plasticity factor will in no way influence the grain. This explains why the grain planes have strikes more constant than any other structural feature in the district.

There is, however, an added cause for the great constancy of the strike of the grain in comparison with that of the cleavage. Grain actually marks the vertical sides of muscovite and chlorite flakes, parallel to the *a* axes, while cleavage marks the almost horizontal basal pinacoids. The slaty rocks, after developing cleavage and grain, were again distorted, as will be mentioned in what follows. Wherever, after the appearance of almost horizontal cleavage and nearly vertical grain, the second compressive force varied ever so slightly from the direction taken by the first compression, the gently inclined cleavage planes were given a markedly different strike direction. On the other hand, the nearly vertical grain suffered but slight change in strike. A simple illustration of this principle is afforded if a book be held with its flat surfaces gently inclined to the horizontal and its two longer edges vertical. The flat surface then represents the cleavage, the longer edges the grain. If pressure is now applied to one corner of the book, so as to bend down that corner, the strike of that part of the book's "cleavage" that is so bent diverges noticeably from that of the unmoved part; the strike of the "grain", however, changes only very slightly if at all.

SHEAR ZONES

Description.—Shear zones are zones inclined to the true cleavage of the slate, along which the cleavage has been sharply distorted. The result is that when the slate is split along the cleavage, a surface is produced which shows a small wrinkle crossing it. Generally false cleavage is developed also in planes paralleling the axis of the fold. In fact, shear zones are merely zones of closely spaced cleavage plication and false cleavage. A sketch made from a specimen, is given in

[75]Bucher, W. H., The mechanical interpretation of joints: Jour. Geol., vol. XXVIII, pp. 707-730, and vol. XXIX, pp. 1-28, 1921.

Figure 13. In the case illustrated, small-scale thrust faulting appears to have taken place along the fracture cleavage planes on the lower limbs of a tiny "anticline" developed in the slaty cleavage. There is also a tendency toward the thickening of slate between cleavage planes on the crest of the small "anticline." In a word, the picture is one of typical thrust folding, except that slaty cleavage plays the role of bedding, while false cleavage simulates the appearance of typical slaty cleavage in its relation to the fold.

Occurrence.—Such zones were noted in regions where false cleavage was well developed, notably in the railroad cut north of Delaware, N. J.

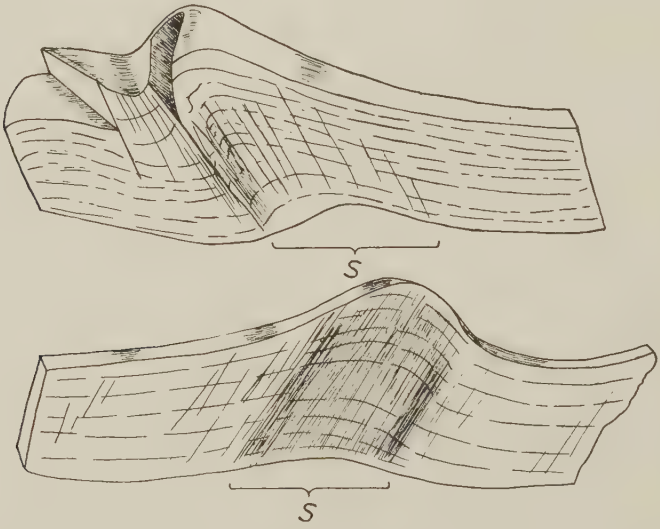


Figure 13. Two views of a cleavage flake of slate showing a shear zone (S), and the associated false cleavage. The shear was more intense at one end than at the other. From Lehigh Valley Railroad cut, a mile southwest of Treichlers station, Slatington quadrangle.

Origin.—This type of structure is explained as shear in rigid material.[76] Its close resemblance on a larger scale to the microscopic appearance of false cleavage, as well as its association with false cleavage and with curved slaty cleavage, point toward a common origin for both, namely by compression of slaty cleavage. It is due to a later stress, then, than that producing the cleavage.

FAULTS

Types of faulting.—If faulting be regarded as movement of one solid rock mass past another along a definitive plane or planes, six types of such movements may be recognized, which, although not

[76]Dale, T. N., Slate in the United States: U. S. Geol. Survey Bull. 586, p. 44, 1914.

all faulting in the strictest sense, can yet best be treated under this head. These six types are:

1. Faults of large displacement and great horizontal extent, approximately parallel to fold axes.
2. Smaller faults of moderate displacement, inclined to the fold axes.
3. Bedding-slip faults.
4. Small-scale faulting in calcareous beds.
5. Movement along bedding planes, —not true faulting.
6. Movement along cleavage planes, —not true faulting.

All of these except Types 1 and 2 are of common occurrence in the district, and hence no attempt will be made to describe all occurrences of the latter four kinds of movement. A short description of each of the occurrences of Types 1 and 2 will be given, however.

The simplest fault nomenclature is preferred. Fault plane, strike and dip of fault plane, hanging wall and foot wall are self-explanatory; normal and reverse faults are terms well understood. Throw is the vertical component of the displacement along the fault plane; heave is the corresponding horizontal component.

Faults of large displacement and horizontal extent.—Of these there are only two in the district. One enters the region studied at Delaware River about nine-tenths of a mile south of Slateford, and extends southwestward so as to have a surface trace trending about N. 45° E. West of Delaware River the evidence for this fault is almost wholly lacking, although a sharp escarpment of twenty to forty feet, four-fifths of a mile north of Portland where limestone from the south probably comes against hard slate to the north suggests its presence. In drilling for the piers of the Delaware, Lackawanna and Western Railroad bridge a mile above Portland, slate alone was encountered. The trace of the fault therefore passes south of the bridge.

In the valley of Jacoby Creek west of Portland and in a large pit about 700 feet south of the post-office of that town, upper Cambrian limestone, dipping gently southward, is exposed. Just across the river, in the railway cut east of Columbia more of the same limestone is seen. Three-quarters of a mile north of Columbia and about half a mile east of the river Cambrian limestone is again seen in the railroad cut of the Delaware, Lackawanna and Western Railroad. About 1¼ mile due west of Hainesburg, N. J., a northward trending road zigzags upward to an altitude of 540 feet. Here the hill on the east side of the road is covered by Cambrian (probably Allentown) or early Ordovician limestone, while on the western side a small quarry exposes typical closely banded hard slate, striking N. 55° E., and dipping 28° N. The fault plane is thus clearly limited on the surface

to a strip not over 50 feet wide. It seems most probable that the limestone here exposed is in about the top of the Allentown. The maximum thickness of beds lacking between the Allentown and Martinsburg are:

Jacksonburg limestone	550 feet
Beekmantown limestone	1,250
Total	1,800 feet

Assuming a dip of 10°, the vertical throw of the fault is at least 1,850 feet.

The dip and strike could nowhere be determined with accuracy. As the fault is associated with an intense folding, and parallels in a general way the strike of the beds, and as the strata appear to have assumed an increased northerly dip as they approach the plane of movement, the assumption appears justified that this is a reverse or thrust fault. Reasoning by analogy with other Appalachian faults, the dip southward is probably gentle. As its trace on a fairly level surface trends N. 45° E., this may be assumed as the approximate strike.

The eastward continuation of this fault has been mapped by the geologists of the New Jersey Geological Survey[77] who regard it as a "thrust fault along which the slate has been pushed over upon the Kittatinny limestone for a short distance."

About half a mile south of Portland, on the west side of Delaware River and west of the Delaware Water Gap highway there is evidence of another fault. The eastern continuation of this, too, has been mapped by the Geological Survey of New Jersey. The western extension trends about S. 50° W., between a quarry opened in the lower, bryozoan-rich part of the Jacksonburg and the lower beds of the Martinsburg, chips of which are exposed at 400 feet on the hill to the south. The fault trace can be followed on the east side of Delaware River by similar evidence, but on the western side the glacial cover is too heavy and the only positive evidence for faulting is the line of springs that appears at the foot of the slate escarpment between Mount Bethel and the river. Westward this fault probably merges with the westward extension of the thrust fault first described, which, judging by the apparent westward thickening of the middle, sandy member of the Martinsburg formation to the north, dies out somewhere in the neighborhood of Ackermanville.

The plane of the fault last described is not exposed anywhere; it is noted, however, that the southwest quarry of the group of quarries in the field half a mile south of Portland shows lower Jacksonburg

[77]Kummel, H. B., Report on Portland Cement Industry: New Jersey Geol. Survey, Ann. Rept. for 1900, pp. 63-65, 1901.

limestone dipping very steeply southward, heavily slickensided in places and bearing every evidence of being dragged downward by faulting. It is evident that the slate moved down against the Jacksonburg, and in so doing dragged the beds of the latter into this steep southward dip. The throw is certainly less than 500 feet. The strike may be assumed to be about N. 50° E., paralleling the trace. As this seems to be a normal fault, the dip is probably steep.

It is highly probable that there are within the Martinsburg other thrust faults or large-scale normal faults, but these are generally not recognizable because of the limited exposures and the difficulty of recognizing displacement due to the absence of beds traceable from place to place.

Smaller faults of moderate displacement.—In the quarries of the Pen Argyl group there are at least five definitely recognizable smaller faults which strike at large angles to the general strike of the beds and have displacements not exceeding 70 feet. These may be seen in the Albion Vein quarry, and in the Jackson Bangor No. 5, 6, and 7 quarries.

In the Albion Vein quarry at a depth of about 490 feet below the surface the trace of a small fault appears in the southwest wall. Here the beds have been broken and the upper beds appear to have moved northward over the lower, the total displacement along the fault being apparently about 16 to 24 inches. The strike of the fault appears to be about N. 25° E., and the dip 35° S. The fault plane is grooved and slickensided with striae that trend approximately parallel with the dip of the fault plane. The drag of the beds along the fault plane is irregular, and suggests that the beds above the plane first moved southward, then north. The fault plane itself is highly compressed, but joints dipping steeply southward are developed along the plane and, though greatly distorted, are preserved, filled with quartz and calcite. These joints fall into two systems, —one nearly vertical, the other dipping 45° S., and cutting and offsetting the vertical joints so as to make it appear that the upper part of the latter moved southward. It is thought that the vertical joints indicate a southward tensional movement of the beds along the fault, which was followed by a compressional movement that opened the inclined joints and offset the earlier system. The offset produced by this fault is too small to be indicated even on the detailed map.

The Jackson Bangor No. 7 quarry was inaccessible. However, it is said to show a fault at a depth of about 160 feet. The movement is reported to carry the Little Hard big bed above against the Genuine big bed below; the displacement is thus northward and about 70 feet below the fault plane, if the movement is normal to the strike of the beds. The plane of this fault is said to parallel that of the similar fault in the Jackson Bangor No. 6 quarry which strikes N.

10° W., and dips 25° NE. If the fault intersects the 160 foot level of the quarry near the middle of the quarry, it should appear at the surface about 150 feet west of the western quarry wall.

In the Jackson Bangor No. 6 quarry on the lowest level (depth, about 345 feet) a similar fault, but with smaller displacement, is seen on the quarry floor and on the northwest wall. Its strike is generally N. 10-27° W., and the dip is 25° NE. The beds on the under side of the fault have moved northward about 9 feet along a line normal to the strike of the beds. As there seems to have been a horizontal component to this motion, the actual displacement in the fault plane was probably greater, 38 feet along the striae of the plane, which trend 60° W. The fault plane is tightly closed, and in many places scarcely recognizable or seen only as a very faint crack.

In the bottom level, in the extreme southwestern corner of the same quarry, a small part of a new fault surface was exposed by channel cutting in December, 1923. This strikes N.35° W., and dips 15° NE. It is approximately the proper level to represent an eastward continuation of the fault described in the Jackson Bangor No. 7 quarry. The striae observed trended N.25°W., approximately parallel to the strike of the fault plane. As the beds below were not yet exposed, the offset could not be measured.

The difference between the direction of the striae in the two faults seen in the Jackson Bangor No. 6 quarry may be explained by assuming for the hanging wall of both a horizontal southward movement and for the upper fault a downward movement as well.

The true movement along these two faults, as far as can be ascertained, is qualitatively represented in Figure 14, in which diagram A represents the lower fault and diagram B, the middle. The front face of both diagrams has a strike of N.30°E. and the direction of the striae is indicated on both diagrams. In addition diagram B shows why the displacement measured along the striae (pn) is greater than where measured along the strike of the fault (mn).

Presumably these faults combine to form the fault of larger displacement mentioned as affecting the Jackson Bangor No. 7 quarry.

Between the present working levels of the Jackson Bangor No. 6 quarry and the bottom of the Jackson Bangor No. 5 quarry a fault occurs, the trace of which may still be seen in the southeastern wall of the Jackson Bangor No. 6 opening, as well as along the northeastern wall. Its plane, though not accessible, was estimated to strike N 20°W., and to dip approximately 55° NE. Along the northeastern wall the displacement appears to be 4 feet, the upper part being moved back that distance, but the movement, to judge by the similar faults already described, was probably largely horizontal and far greater than it

appears to be in this section. It is said by quarrymen to have offset the beds more than 100 feet.

A similar fault occurs in the northeastern (northern) corner of the Jackson Bangor No. 5 quarry. Its trace is clearly seen high on the wall of this quarry. The offset is not known, but it is said that in this instance the beds above the fault plane moved north.

It thus appears that there is a system of faults trending northwest or north and with largely horizontal displacement. These may be as late as Triassic in age, or may represent post-Martinsburg or post-

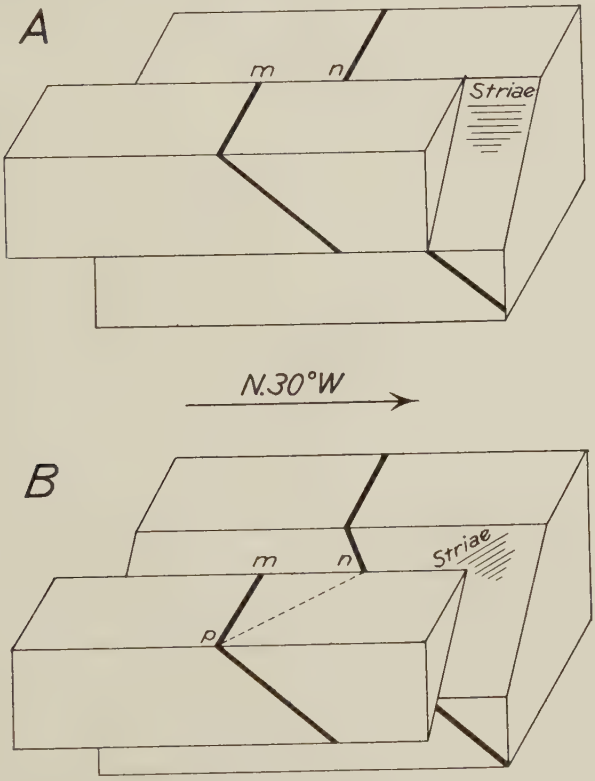


Figure 14. Diagrams to show relation of striae to direction and amount of displacement of faulted blocks in Jackson Bangor No. 6 quarry. A,-lowest fault, with striae trending about N.30°W.; B,-middle fault, with striae trending N. 60°W.

Carboniferous relaxation after a period of thrusting. Or finally, they may actually be high-angle thrust faults that relieved a horizontal compression by permitting the forward movement of individual segments. The last explanation is, in the light of facts so far obtained, the most acceptable.

Bedding slip faults.—These are faults which are associated with close folds, and in which most of the movement takes place at such a

low angle to the bedding that an actual plane of faulting distinct from the bedding planes can be recognized with difficulty, if at all. For such faults the term bedding slip is here proposed. Some of the features referred to as "loose ribbons" by the quarrymen are bedding slip faults. The attention of the observer is first directed to the fault when he finds that the attitude of the upper (inner) beds in a close syncline is not like that of the lower beds. Closer inspection then reveals the fact that near the axis of the fold these upper beds describe a larger arc than do the lower ones, hence that the lower strata are truncated by the upper ones. Associated with this feature is generally a severe mashing of the beds, with irregular cleavage, closely spaced jointing, and much deposition of quartz and calcite in open cavities.

Examples of this feature are numerous. The north wall of the Albion pit is perhaps the most striking case in the region, rivalled only by the north wall of the Bangor Vein (New Peerless) quarry. There is a suggestion of the same feature in the north wall of the Jackson Bangor No. 6 quarry near the surface. The Albion Vein quarry has its north wall similarly formed. The Bangor Fidelity and West Bangor quarries show a slip fault along the bedding about the middles of their side walls, and traces of its continuation are preserved in the Crown quarry to the west. Finally, a trace of a similar feature is to be seen midway between the "back" and "front" ends of the opening in the northeast wall of the Northampton quarry. Mention is made of this type of faulting in the descriptions of each of these quarries. Two outstanding examples may here be described, however.

In the New Peerless (Bangor Vein) quarry, the beds curve sharply into a syncline having an axis that dips southward only about 8°; the general bedding strike is N.40°E. Immediately south of the north wall of the opening, the beds curve gently in the trough of the syncline and the cleavage surfaces are horizontal and plane, but 10 feet farther south the dips of the synclinal limbs flatten and the cleavage becomes crenulated, as though greatly compressed after its formation. A sketch of this part of the fold is shown in Figure 15, A. The fault plane itself approximately parallels the northern, less compressed beds and is open in places, with a filling of quartz and calcite, much of the latter having been dissolved away subsequently.

In the Albion quarry the northwestern wall is cut into a series of reentrants. At about the middle of this side of the opening there is a remarkably smooth bedding face. The bedding north of this face curves gently to form a rather open syncline, but southward the fold is more tightly compressed, with a noticeable bulge at the axis. Heavy and closely spaced jointing is conspicious at the bedding surface marking the contact between the more tightly and the less severely

compressed parts of the fold. The plane of contact strikes N.57°E., and varies its dip with the bedding. It is heavily slickensided and coated with quartz and calcite. Vertical joint planes are well developed under the axis of the fold; above it they are similar, dipping 80°S. For a diagram of these relationships, see Figure 15, B.

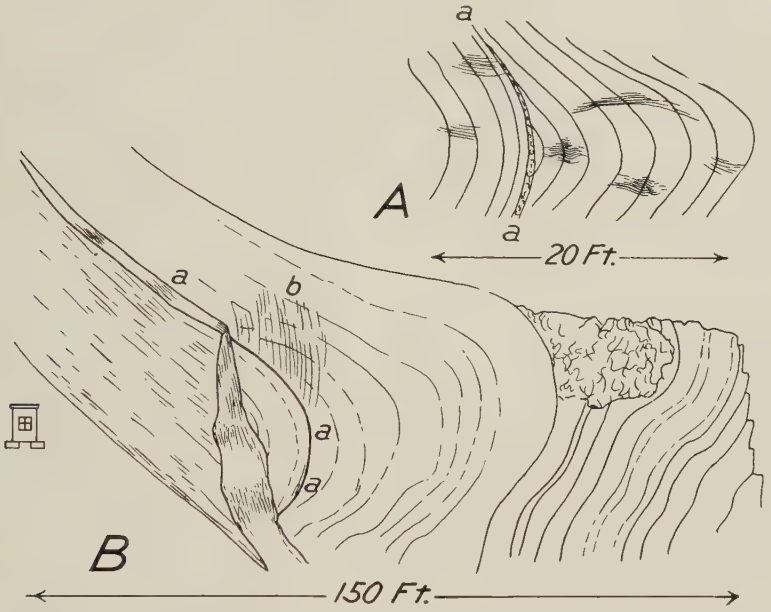


Figure 15. Bedding slip faults: A, in Peerless quarry, northeast wall; shows bedding slip plane (a-a), the lower part of which is a quartz filled crevice; B, in Albion quarry, viewed from southwest wall; shows fault plane (a-a) and vertical joints (b).

A diagram of an idealized fault of this type is given in Figure 16.

Figure 16. Diagram of ideal bedding slip fault; b-b, fault plane; arrows show apparent direction of movement.

Movements of this type can best be interpreted as a way of relieving excessive pressure in the fold axes. The attitudes of the beds and the jointing suggest that bedding slip faults were means of permitting bulging in the lower beds of troughs. The disturbed cleavage proves that the movement took place after sericitization; if the period of cleavage development of the slate be regarded as post-Martinsburg, pre-Shawangunk, these faults must clearly represent an adjustment to thrusts of a deformative period much later than the Martinsburg.

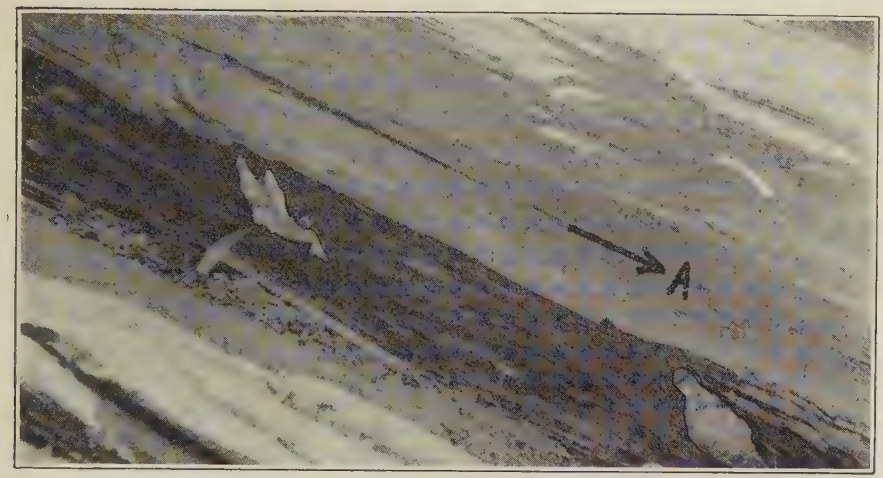
Small-scale faulting in calcareous beds.—In many places the occasional calcareous beds are broken by numerous faults, which have approximately horizontal planes. In such instances each little segment of the limy bed has glided over that beneath it, so as to yield many small faults, which, as they parallel the axes of tiny drag folds, may be spoken of as "drag faults." It is significant that the faults never pass into the slaty beds on either side, but die out at the edges of the calcareous beds, although a parallel suite of drag folds is sometimes visible in the slate adjoining the limy bed. The fault planes in the calcareous beds are generally coextensive with the cleavage.

An illustration of this type of minute faulting is given in Plate VIII, A, and in Figure 17.

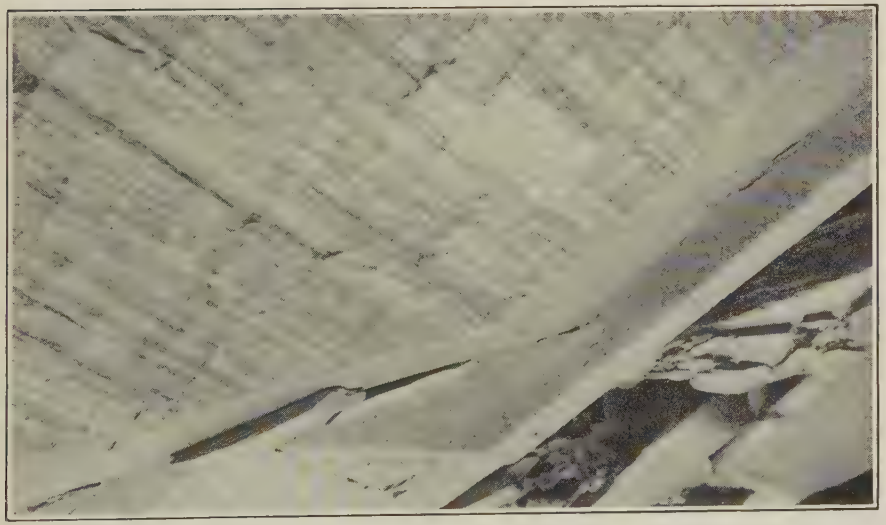
PLATE VI

A. Small-scale faulting in calcareous beds; the adjacent slate beds are much folded; length of specimen, 6 inches.

PLATE VIII



B. Zone of movement along cleavage plane, lowest level, Belfast quarry. Two quartz lenses are seen, one being marked by the hammer head. Direction of cleavage indicated by arrow.



C. Striae or slickensides on a calcite-coated bedding plane in an old quarry near Slatington, Pa. Shows the effect of bedding plane movements.

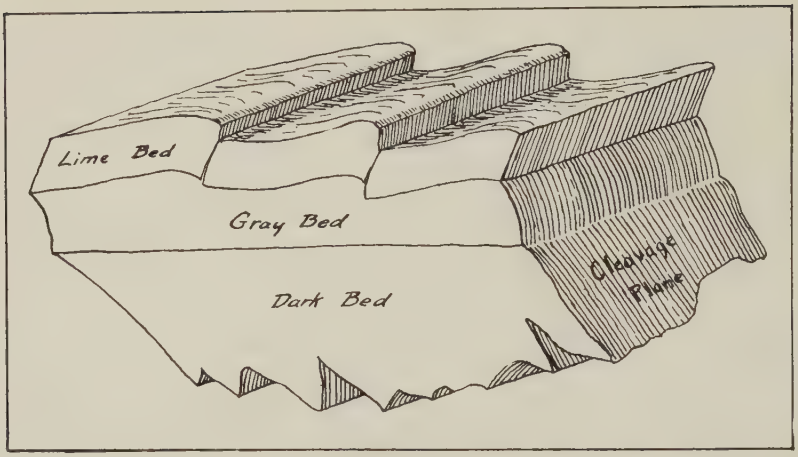


Figure 17. Mullioned calcareous bed, closely faulted, and undistorted slate beds below it. The upper surface of the specimen is heavily striated. Length of specimen, 10 inches.

Movement along bedding planes.—In a series of beds as severely folded as those of the Martinsburg, movements along bedding planes are to be expected and are, indeed, of common occurrence. They are particularly noticeable in the middle, sandy member, where they are commonly associated with false cleavage and with "wrinkling" of the bedding surfaces. They are also commonly seen in association with the rather calcareous beds in the soft slate. These calcareous beds are called by the quarrymen "silver ribbons." As they are subject to solution by percolating waters, they commonly become separated from the slate beds on either side, leaving a discontinous crevice, along which the slate parts; in such cases, the quarrymen refer to the calcite beds as "loose ribbons." A surface of a loose ribbon commonly bears slickensides or striae, showing that movement has taken place along it.

Movement along cleavage planes.—The movement along cleavage planes is considerably evidenced in the slate. This evidence is most noticeable in the hard slate. Here it is not uncommon to find quartz or calcite lying in the cleavage, and occasionally striae are still preserved on the cleavage filling. In places, joints suggestive of tensional cracks and also filled with calcite, quartz, or a mixture of both, cut the cleavage vertically in such a way as to suggest tensional joints; as they die out both above and below, the suggestion is that either their upper or lower ends mark the intersection with the cleavage plane along which slippage took place.

An illustration of such movement is seen in the east wall of the Belfast quarry. Here a zone about ten inches wide has undergone

shear along the cleavage, with the development of openings and deposition of quartz in the openings so formed (see Plate VIII, B).

JOINTS

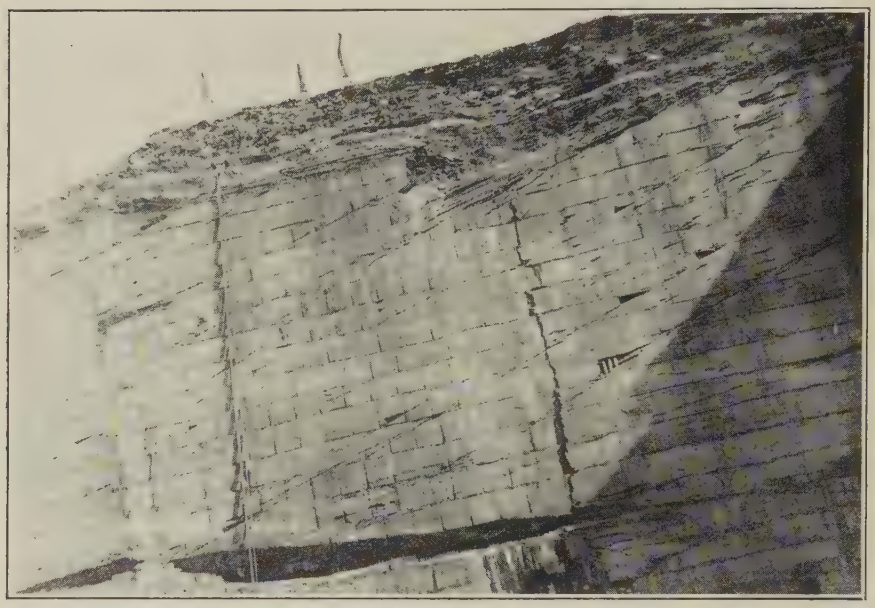
Description.—In folded sediments, joints may be classified in various ways. Thus, they may be separated into "compression joints" and "tension joints". This is generally unsatisfactory, as it requires a demonstrated relation to stress. A classification of joints based on their field relations to bedding, e. g., "strike joints," "dip joints," and "oblique joints," is meaningless, as some purely arbitrary limit must be set to the use of each of these terms.

In these studies much effort was spent in attempting to find a generalization that would assist in the interpretation of the numerous joints observed. A purely empirical method was followed, and no classification was resorted to. Many observations were made and, where joints were plotted for small areas, they were seen to fall into definite groups or systems; however, no satisfactory rules by which jointing could be anticipated were discovered in the district. The reason for this is probably three-fold: (1) the joints may be due to two separate orogenic movements; (2) the stresses vary from place to place in closely folded beds, such as these; (3) special features, such as bedding slip faults, are coincident with joints, the distribution of which is thus a response to highly localized stresses.

The joints observed are of two general types,—one in which the planes are very smooth and regular, the other in which the planes are warped surfaces or possess ridgelike protuberances where bedding is crossed. Some few joints are horizontal, but these are not common. Some joints are coated with calcite, as in the Tinsman quarry; others bear pyrite lenses, with the long dimensions parallel to the strike.

Joint systems.—Strikes and dips of numerous joints were plotted for all quarries examined. Twenty-five quarries yielded joint patterns in which the conspicuous feature is the large number of northeastward bearing strikes. Examples of regular joint systems are afforded by the eastern part of the southeast wall in the Albion quarry (Plate IX, A); by the beautifully rhombic joint intersections of the Albion Vein and Pearsons quarries; and by the east wall of the Consolidated No. 1-Star quarry (Plate IX, B). Yet, though in these joints there is always a suggestion of definite systems, even in joints with the same strikes the dips are not uncommonly divergent. The chief significance of this predominant northeastward bearing of joints is that the forces producing them were similarly directed with those producing the slaty cleavage. Further empirical observations are given in the section on the economic geology of the slate, and in the description of quarries.

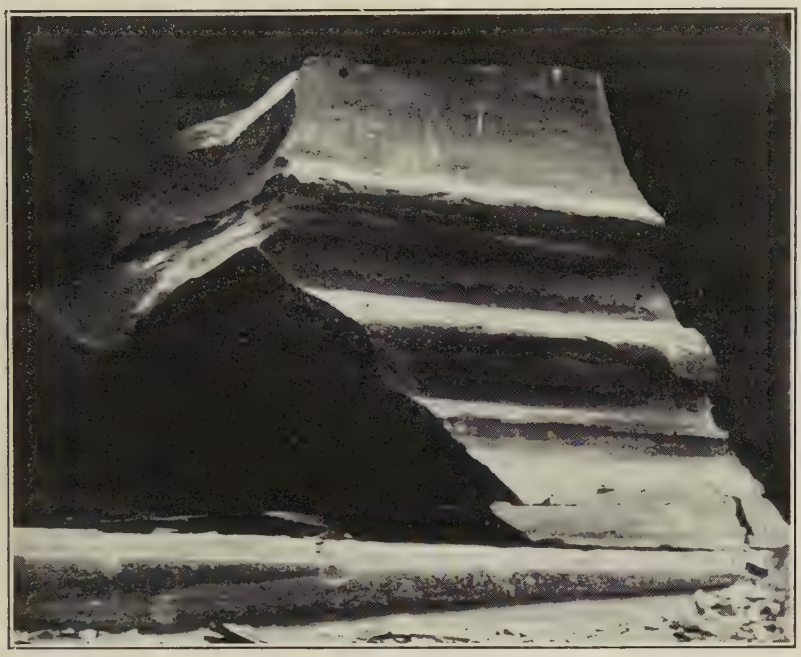
PLATE IX



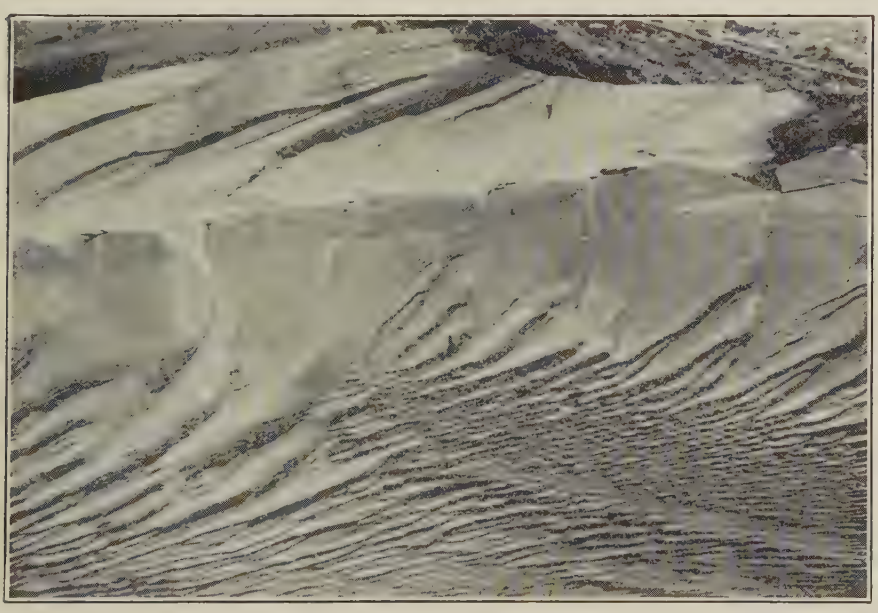
A. Regular jointing in upper part of southeast wall near east corner, Albion quarry.

B. Part of northeast wall of Consolidated No. 1-Star quarry, showing numerous joints striking N. 30-35° E.

PLATE X

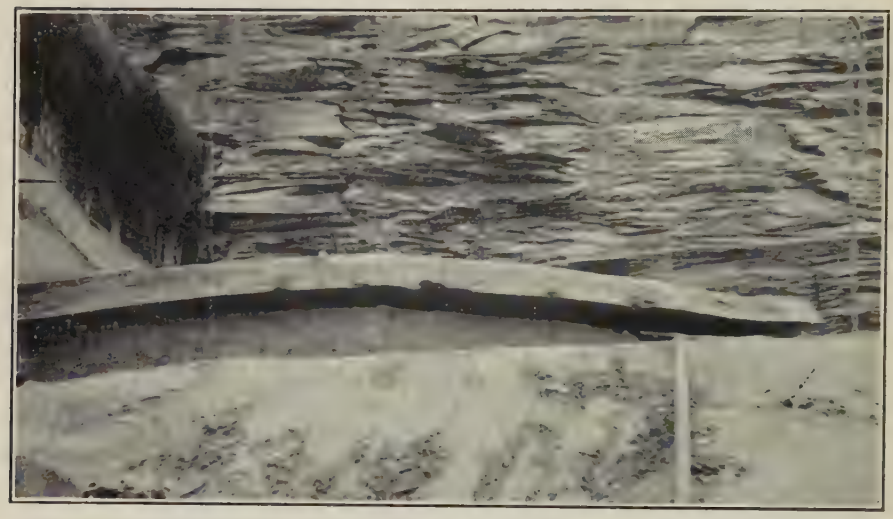


A. Joint surface, curved where it crosses beds of varying composition. Height of exposed surface, 2 feet. Albion quarry.



B. Joint surface, "wrinkled" and cut by minor joints. Length of exposed surface, 6 feet. Columbia Bangor quarry.

PLATE XI



A. Gently curved cleavage. This slab can be used despite the curva ure of the cleavage. New Peerless quarry.

B. Relation between cleavage ("split"), bedding, and grain in a block of slate. The surface in the plane of the page is grain. Traces of bedding (B) and of cleavage (A) are visible in the plane of the grain.

Joints associated with bedding slip faults.—There are generally numerous joints, very closely spaced, associated with bedding slip faults (See Figure 15, B). They are apparently shearing effects produced by the drag of the beds moved along the fault plane. They are invariably nearly vertical and appear to follow the rule that the acute angle between the bedding slip fault plane and joint plane points in the direction of movement of the beds affected by the joints*.

MINOR STRUCTURES

"Catspaws" or "blisters".—These are features showing on the cleavage faces of slate, resembling very low domes that have heights of less than an inch and diameters not exceeding one foot; instead of rising to their peaks with gradually convex slopes, they rise above the normally flat cleavage by a series of steps which form concentrically around the tops. They resemble the percussion marks made in flint when the latter is chipped, —the reverse of conchoidal fracture; they may be coated with iron-stained calcium carbonate.

Features of this type, though common in the quarries at Slatington, are but rarely observed in the region studied. They are seen locally, however, especially in the old quarries of the Slatefield group and in the Arvon and New Bangor quarries.

Fractures of the same shape have been made in flint--another dense, fine-grained rock—by human and natural agencies, when stone is struck against stone. They almost suggest the effect of sudden pressure. They might be assigned to blasting, but that the cleavage gives no evidence of distortion, and open cracks in the near neighborhood are lacking; further, their localization would remain to be explained, as blasting is a common practice in all the quarries. Such "blisters" appear to have been produced by sudden shocks, possibly such as earthquake vibrations, whereby one part of the slate is forced sharply against another in such a way that the rebound slightly separates the cleavage where the highest part of the dome or "blister" now is.

"Watersplits".—These are crevices, similar to joints, but less regular, forming generally very low angles with the horizontal and with the cleavage. They appear in quarries after a smooth and extensive cleavage surface has been exposed to the air, and especially when one or two of the quarry sides are freed by channel cuts. By the quarrymen they are attributed to the action of the water working its way through the slate. It seems improbable, however, that water itself can form openings in so insoluble a material. Nor is capillarity known to act so as to separate the two sides of crevices. Another possible water

*Willis, Bailey, Geologic structures, p. 179, 1923.

force is hydrostatic pressure; but this, it seems, should be more effective along joints, cleavage planes, or other pre-existing fractures. Water is known to freeze in the cracks and, with the expansion incidental to the formation of ice, to force the rock masses asunder; but here, again, pre-existing crevices must be appealed to.

It is necessary, therefore, to find some other cause for the openings. When a quarry has reached some depth, the overburden is greatly reduced in the opening, but still exists on the sides. There is thus a relief of pressure within the confines of the quarry, which permits the slate in the quarry floor to bulge upward slightly for one or more of the following three reasons:

1. The buried slate is normally under great pressure, due to the rock above; when this is removed the slate "springs" upward.

2. The walls of the quarry, no longer held apart, now that the slate has been removed from the quarry, creep inward and buckle up the slate in the quarry floor.

3. Pressure exerted near one end of the top of a pack of cards tends to lift and separate the cards at the opposite end of the pack; in a similar way, the rock presses downward and separates the slate along the horizontal planes; this can, of course, only be effective when one side of the slate is free.

Probably the sudden appearance of "water-splits" is best accounted for by the second and third explanations.

Similar movements in rocks in the course of quarrying have been noted elsewhere. Thus, Buckley and Buehler[78] describe the gradual closing of channel cuts in limestone quarries, as follows:

"At the northeast corner of the quarry the lower beds give evidence of being under slight stress. When making the opening or head cut north and south on each of the three lower channel cuts, it was found that as this cut deepened it closed perceptibly, and smaller bits were necessary to continue the work. The effect was noticed after the stone had been channeled from two to three feet from the top of the bed. The stone for about eighteen inches on each side of the channel cut showed many fine joints parallel to the bed."

[78]Buckley, E. R., and Buehler, H. A., The quarrying industry in Missouri: Missouri Bur. of Geol. and Mines, Report, vol. II, 2nd Ser., p. 127, 1904.

METAPHORISM OF THE SLATE

SUMMARY

When sufficient pressure is brought to bear on clay sediments they are altered in mineral composition. This alteration expresses itself chemically by the very general absence of the more soluble constituents and by some loss of water from hydrated molecules; such changes have the effect of increasing the density of the individual crystal grains. Physically the alteration is expressed by an intense compacting of the rock matter, the chief evidence for which is the development of crystal forms that are thin flakes, rather than grains. Incidental to compacting, minor adjustments take place throughout the body of the rock, so that granular minerals are sheared, rolled, or comminuted, all of these processes being methods of adjusting them to increased stresses. Such changes in rock masses induced by an increased pressure as primary agent are called dynamic metamorphism. Slate is thus produced.

Slate is in most cases a clay sediment that has been subjected to stresses other than those of simple gravitation. Thin sections of slate as seen under the microscope are thus characterized by:

1. General compactness.
2. Granulation, shear, or other evidences of strain in particles that have all three dimensions approximately equal, and
3. Parallelism in the directional orientation of flat minerals, which are either developed during the metamorphism or, having been present before the pressure was initiated, are turned in such a way as to have their flat or long surfaces arranged parallel.

Chlorite and sericite are two minerals commonly found in slates and showing a marked tendency toward the development of such flat surfaces.

DETAILED DESCRIPTION

Minerals of the slate.—As stated in the section on the composition of the slate, the minerals found in the slate of the region studied are quartz, calcite (probably magnesia-bearing), muscovite (sericite), chlorite, plagioclase, biotite, rutile, pyrite, magnetite, graphite, zircon, and probably kaolin and limonite.

Of the quartz two types can generally be recognized: Type 1 shows fracturing or strain shadows in many instances, generally stands out with well marked boundaries against the groundmass, and frequently bears conspicuous numbers of small inclusions (rutile needles, bubbles, and the like); the individual grains are large and rounded, with all three dimensions approximately equal. This type of quartz has been

largely replaced by calcite. Type 2 is in smaller particles, the edges of which fade irregularly into the unresolved groundmass, being intergrown with muscovite and chlorite; there are no strain shadows and no granulation is seen with certainty. The calcite cannot be said to replace this quartz, although the hazy crystal boundaries of the latter make this fact difficult to ascertain. Inclusions in the second class of quartz are rare.

Calcite is generally in rhombs or in irregular masses replacing the quartz, or filling crevices between minerals or crystal fragments.

Muscovite is in shreds, weaving between the granular minerals. In many places it shows a border of chlorite. It is possible that some of this mica is paragonite, the soda mica.

Chlorite appears as shreds or threads enmeshing the granular minerals. It also occurs in lenticular areas, with well defined cleavage; in the latter cases the cleavage gives the mineral the appearance of slender flakes laid side by side and not uncommonly one or several of these flakes (generally the more central ones) show the high interference colors, parallel extinction, changing relief, and paleness of muscovite; in the centers of such lenses traces of the pleochroism of biotite, with clouds of limonite nearby, are still to be seen. The chlorite is largely an alteration product of biotite.

Plagioclase is generally fresh. Biotite is present only in remnants in the chloritic lenses. Rutile occurs as primary inclusions in quartz, but is occasionally found in calcite, where the quartz is replaced by the carbonate, and is also scattered through the mass of the rock with chlorite and mica. Pyrite, magnetite, and graphite occur in spherules. Magnetite locally shows as fillings in the center of chloritic areas, forming tiny veinlets, much like those of chrysotile asbestos in serpentine.

Zircon is present in rounded grains.

Inclusions of primary apatite are seen in the quartz grains, but are not of importance in the problem of metamorphism.

Deformations.—The correct interpretation of rock changes is at once the noblest and most difficult phase of petrology. In the problem in hand it can be accomplished only by a study of the micro- and megascopic structures of the slate. At the very outset, the problems raised appear to be insurmountable, and even extended scrutiny of thin sections makes the answers more nearly interpretations than final solutions.

In this research the effort was made to follow the sequence of mineral development in metamorphism. It has been pointed out in the section on structural geology that two periods of compressive deformation are recorded in the larger structures of the slate. It is believed that microscopic evidence favors the same interpretation because of the

presence of two suites of metamorphic minerals. The mineral suites of the two apparently distinct metamorphic periods may represent a rather continuous process in two steps beginning with clay and ending with the slates of today. But since field evidence favors two separate deformations and micropetrography appears to demonstrate two stages in metamorphism, it seems logical to assume correspondence between the second metamorphism and the second deformation. That the first orogenic and metamorphic periods were about coextensive in time cannot be doubted.

Primary minerals.—Of the minerals listed, those that were originally present in the rock are: quartz (type 1), zircon, plagioclase, carbon, biotite, some magnetite, rutile and apatite inclusions in quartz.

Quartz and zircon are highly rounded and are clearly transported sedimentary grains. The same explanation probably applies to magnetite. The biotite is in masses comparable to the quartz grains in size and shows little if any actual parallelism in orientation, yet such orientation might be expected had the mineral been of metamorphic origin. The carbon probably represents organic matter mixed with the muds and clays when the sediments were laid down.

Unquestionably much clay was present in the original sediments, but only the minerals derived from it now bear evidence of its earlier presence.

Physical changes induced in first period of metamorphism.—When these sedimentary minerals underwent their first severe compression, some were altered into substances described below. Others, however, suffered little chemical change, being merely broken or distorted. Others again were both deformed and chemically metamorphosed.

The quartz, having no gliding planes along which movement could readily take place and being a compact, relatively insoluble mineral, underwent internal molecular or supermolecular strains and was fractured or even comminuted.

Biotite, on the other hand, was not only chemically altered, (see below), but, because of its flexible character, was deformed as well, so that its cleavage is curved and its flakes frequently highly bent.

Chemical changes induced by first period of metamorphism.—Under the severe pressure set up by the deformations that shattered the quartz and bent the biotite, chemical changes were also effected. It appears from a study of the thin sections that the biotite was almost completely altered, being sericitized and perhaps partly chloritized; this change is shown occasionally by traces of partly bleached biotite in the centers of lenticular masses of chlorite; in the latter the cleavage is parallel to that in the biotite and occasional cleavage flakes are muscovite (sericite) instead of chlorite. The writer is aware

that the change from biotite to muscovite has not been recorded and that a satisfactory explanation of the source of potash in the muscovite cannot be given. It is pointed out, however, that the iron and magnesia of the biotite may well have entered the chlorite, while all analyses of biotite yield some potash; further, potash has a peculiar affinity for clays[79], which especially favors the formation of muscovite. Hutchins[80] has shown that the white mica of clay slates is very impure, containing iron, magnesia, and soda.[81] It seems reasonable to conclude, therefore, that the first change affecting the biotite was an alteration to muscovite, and perhaps in part to chlorite.

At the same time the clay of the original sediment was undergoing conversion into muscovite (sericite). Granulation and fracturing of the quartz resulted in the opening of crevices between adjacent parts of a quartz grain, and the ubiquitous muscovite appeared here as well. An illustration is furnished by Figure 18.

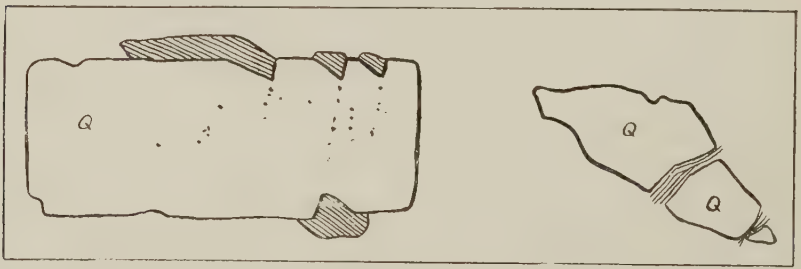


Figure 18. Microscopic appearance of secondary sericite filling crevices in primary quartz. The "shredded" mineral is mica; Q, quartz. New Diamond quarry, Pen Argyl. X 350.

Synchronously secondary quartz began to develop throughout the rock mass, filling what spaces were created by the removal of the soluble minerals. New quartz attached itself to primary quartz grains in the familiar manner of secondary quartz in quartzites.

The development of rutile is probably also to be assigned to this metamorphic stage.

The net result, in short, of the mineralogical changes induced by the first period of metamorphism was the development of clay slate rich in quartz, sericite, and probably chlorite.

Physical changes induced in second period of metamorphism.—Very probably the second deformation resulted in further straining and fracturing of the quartz, but the effects produced cannot be distin-

[79]Leith, C. K., and Mead, W. J., Metamorphic Geology, p. 106, 1915.

[80]Hutchins, W. M., Clays, shales, and slates: Geol. Magazine, vol. III, pp. 313, etc., 1896.

[81]For typical analysis of muscovite, see Iddings, J. P., Rock minerals, p. 420, 1906; also Dana, J. D., The system of mineralogy, 6th Ed., pp. 617-619, 1914.

guished from those of the first deformation. Muscovite masses were warped, bent, or fractured as is seen in Figure 19. At this time

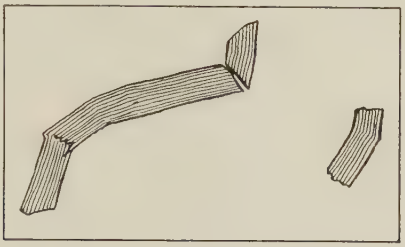


Figure 19. Microscopic view of bending and fracturing in flakes of secondary muscovite (sericite). New Diamond quarry, Pen Argyl. X 350.

also, possibly, were formed crevices in the rock; these were filled with calcite.

Chemical changes induced by second period of metamorphism.—The outstanding chemical change induced during the second metamorphic period was the notable increase in the magnesium content of the rock. To this period probably should be attributed the formation of much if not all of the chlorite into which the sericite of the original biotitic areas was altered. Isolated fibers of sericite apparently not developed from biotite were also chloritized, at least at their margins. In the thin sections examined, it is common to find an area of chlorite surrounding single flakes with the typical high birefringence of mica. Nevertheless, the muscovite is generally still quite fresh, showing no corrosion.

Another change which took place either during or after this metamorphic period was the extensive replacement of quartz by calcite. This is clearly seen in the fractures of the quartz, which are largely filled with calcite, and in the irregular embayments of calcite into quartz. Illustrations are furnished in Figure 20. Locally several

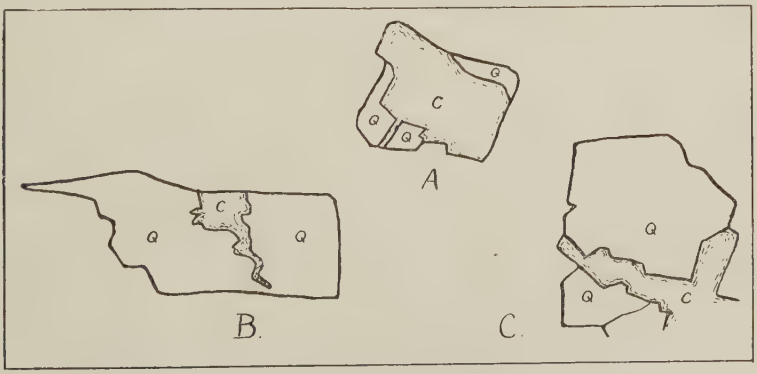


Figure 20. Microscopic grains of quartz (Q), replaced (A and B) or with crevices filled by secondary calcite (C); in each case all of the quartz is part of one crystal. New Diamond quarry, Pen Argyl. X 350.

quartz grains, still showing the simultaneous extinction which proves that they were originally all parts of a single crystal, are separated by narrow strings of calcite. As the calcite shows no gliding along cleavage planes it cannot have been subjected to much pressure since it was laid down.

To summarize:—the effect of this later period of metamorphism—if indeed these changes can be assigned to a separate time interval and are not merely gradationally continuous with the earlier metamorphism—was to alter much of the preexisting muscovite to chlorite and to replace some of the quartz with calcite.

GEOLOGIC HISTORY

SUMMARY

It is not a purpose of this report to detail the geologic history of the rocks in the slate belt. A brief summary only is presented.

After the laying down of the marine Lower and Upper Cambrian sediments, the Lower Ordovician (Beekmantown) limestones were deposited also in the sea. This sedimentation was followed by an uplift, and then ensued another submergence, with the deposition of the shaly limestones and shales of the Jacksonburg and Martinsburg. There followed a period of intense folding, with renewed uplift; at this time the shales were highly compressed and partly at least converted to slate. Then came submergence again, and the laying down of the Shawangunk conglomerate, followed by the deposition of a great thickness of sediments, mainly marine, but partly of fresh water origin. Finally, at or near the close of the Paleozoic came another severe disturbance, the Appalachian revolution. In the horizontal plane the force which caused this was directed similarly to that affecting the region at the close of Martinsburg sedimentation.

There followed a long time during which weathering and erosion affected the rocks of the region. Flat surfaces—the erosion base level of rivers—were formed, the country rose, and the rivers started the work anew; this process of base leveling and uplift occurred repeatedly and is called "peneplanation."

Later yet came the ice of the Pleistocene, removing much of the normal debris that the work of running water and the atmosphere distribute over the surface of the earth; at the same time the ice-borne material from the north took the place of the decayed soil cover.

Since the retreat of the ice, the glacial deposits and the underlying partially decayed rocks have been suffering the usual stream erosion.

PALEOZOIC ERA

Cambrian and early Ordovician sedimentation.—In Lower Cambrian times the region was submerged and a coastal line, not far east of

the area described, was developed. Into this shallow, coastal sea, rivers coming down from the older highlands to the east brought the coarse sands of the Hardyston formation. As the seas deepened and the highlands were worn lower and lower, the sediments became clayey and even calcareous, and the argillaceous limestones of the Tomstown formation were deposited.

This period of deposition was followed by a rise of the sea bottom in such a way as to expose the upper part of the Tomstown to erosion. In Maryland deposition continued for a longer time and other beds of lime and clay are found above the Tomstown.[82]

After some erosion, lasting from lower Middle Cambrian to lowermost Upper Cambrian time, the region was again submerged, again beneath a shallow sea. As no highlands existed nearby, the sediments accumulated were almost altogether calcareous. That they were of shallow water origin is confirmed by the presence of oolites, cross-bedding, and edge-wise conglomerate. These calcareous muds formed the Allentown limestone of Upper Cambrian age.

Later the faunas in the sea changed somewhat, becoming recognizably Ordovician. The magnesian limestone bearing these faunas constitute the Beekmantown formation of this report.

Early Ordovican sedimentation was brought to a close by a lesser uplift, for which the evidence, as presented by the New Jersey Geological Survey,[83] consists of the presence of a marked local unconformity and of rounded fragments of the Beekmantown in the basal beds of the overlying limestone.

Jacksonburg sedimentation.—After some erosion, the land surface was lowered in Middle Ordovician time and sedimentation again set in. Calcareous muds were laid down, and in them life abounded. The fossil forms suggest shallow quiet seas. The irregularity in distribution and thickness of these beds point to their deposition close to the shore.

Martinsburg sedimentation.—By an almost perfect gradation, the calcareous sedimentation of the Jacksonburg gave way in Eden times to the graphitic sandy and calcareous clays of the Martinsburg. The argillaceous and (in the middle member) arenaceous character of the new strata suggests that they were laid down in a shallowing sea or --what is more probable—that the nearby land masses to the east suffered an uplift such that the rejuvenated streams bore more and coarser sediment and carried it farther out to the sea than during the Jacksonburg stage. This uplift apparently attained its climax during the middle of Martinsburg times.

A study of the Martinsburg shales and sandstones suggests several

[82]Bassler, R. S., The Cambrian and Ordovician deposits of Maryland: Maryland Geol. Survey, pp. 66-74, 1919.

[83]Kummel, H. B., Report on Portland cement industry: New Jersey Geol. Survey, Ann. Rept. for 1900, p. 36, 1901.

facts regarding their origin. The finding of brachiopods and graptolites points to their being marine deposits, and as the faunas are not provincial in distribution and contain such plankton as graptolites, it is evident that the open sea was accessible somewhere along the coast.

Very probably the Martinsburg sea was a shallow arm connected with the open Atlantic across Maryland. That it had a fairly constant depth, so that sediment was distributed evenly over most of its bottom, is shown by the uniformity of the sequence, bed for bed.

Shallow water is indicated by the ripple marks, cross-bedding, and rapid alternation of various types of sediments. The remarkable change from graphitic to more purely clayey layers may be explained on the basis of secular variations, or it may be assigned to storms, which stir up the sea bottom and permit the differential gravitative settling of sediments; if the latter explanation be accepted, it is difficult to understand why the contact between the light and dark beds is so sharp.

The presence of thick lenses of limestone in the lower member of the Martinsburg may be attributed to small, deeper pools, not accessible to mud-bearing streams, such as may be found on any irregular shore.

The source of the sediments is not greatly in doubt. The material of which the Martinsburg is composed almost surely came from the east, for cross-bedding everywhere dips westward and current-ripple marks generally have their steeper sides toward the west. A source for the graphite that is so common in the dark beds yet remains to be discovered. The idea is here tentatively submitted that during the summer and fall the vegetation that floated out to the sea added carbonaceous material, while in the winter and spring only occasional bits of plants accumulated in the shallow basin.

Post-Martinsburg erosion.—After the close of Martinsburg deposition, the shales and underlying rocks were probably thrown into folds resembling what is seen today. This was, of course, accompanied by uplift and the withdrawal of the sea. Coincident with the deformation, the shale was very highly sericitized, and probably made into a true slate or at least clay slate.

As the sea withdrew the slate was exposed to erosion and so was made to contribute materials for the next series of sediments.

There is thus a marked post-Martinsburg unconformity. The evidence for this is as follows:

1. The effects of the two periods of deformation can be recognized in the structures of the Martinsburg formation, an earlier which folded the beds and a later which folded the cleavage. As the latter must be post-Carboniferous (there being no Mes-

ozoic or Cenozoic period of intense folding), the earlier is post-Martinsburg, pre-Shawangunk.

2. Two periods of metamorphism of the slate are believed to be recognized on microscopic evidence. To these metamorphic epochs reasoning similar to that employed in the case of the orogenic epochs (paragraph 1, above) applies.

3. Within the basal conglomerate of the Shawangunk, the next formation above the Martinsburg, pebbles of dark slate, with cleavage in the individual pebbles not similarly oriented, are seen. If the pebbles had the cleavage similarly oriented, their presence in the Shawangunk might be attributed to a slight erosion interval and their present sericitization to post-Carboniferous folding; but as it is, these pebbles clearly demonstrate the sericitization of the Martinsburg before the laying down of the Shawangunk conglomerate.

4. The Shawangunk-Martinsburg contact is rarely seen, because of the cover of talus from the conglomerate. But in those places in Pennsylvania and New Jersey where it is visible an unconformity is observed. There is an exposure at the Lehigh Water Gap, where, in the Central of New Jersey Railroad cut, is seen a divergence of 9 - 12° in dip and 15° in strike, with a 30-inch zone of unusually heavy conglomerate in the base of the Shawangunk beds.

   Even with perfect parallelism over short distances between the beds of the two formations in question, the presence of an unconformity is not precluded, as such parallelism may be expected in recumbent folds.

This conclusion has been defended by Miller and Behre[84] following the early work of several geologists, notably Schuchert[85] and White[86], and in disagreement with the view recently advanced by Keith[87].

Silurian and later deposition.—The severe folding at the close of the Martinsburg is further suggested by the coarse and heavy sedimentation at the beginning of the Shawangunk epoch, which is here provisionally referred to the Silurian. Thick conglomerates and sandstones were laid down; these Grabau[88] has referred to deltaic origin.

They were followed by a great thickness of sediments that do not

[84]Miller, B. L., Taconic folding in Pennsylvania; Behre, C. H., Jr., Taconic folding in the Martinsburg shales: Geol. Soc. Am., Bull., vol. 36, No. 1, 1925.

[85]Schuchert, Charles, Silurian formations of southeastern New York, New Jersey and Pennsylvania: Geol. Soc. Am., Bull., vol 27, pp. 531-554, 1916. Ibid., Textbook of geology, Pt. II, p. 660, 1920.

[86]White, I. C., Geology of Pike and Monroe Counties: Pennsylvania Second Geol. Survey, Report G 6, p. 237, 1882.

[87]Keith, Arthur, Outlines of Appalachian structure: Geol. Soc. Am., Bull., vol. 34, pp. 331-334, 1923.

[88]Grabau, A. W., Paleozoic delta deposits of North America: Geol. Soc. Am., Bull., vol. 24, pp. 406-442, 1913.

appear in the region here mapped, and hence may be omitted from this description.

Appalachian folding.—Toward the close of the Permo-Carboniferous (Upper Carboniferous) the strata now composing the Appalachian Mountains were thrown into close folds. This orogenic epoch is spoken of as the Appalachian Revolution. At the Big Offset in the Kittatinny Mountain a westward pitching syncline in the Shawangunk formation is to be attributed to this period of folding; here the beds on the northeastern end of the Offset dip southwestward, while an eighth of a mile north they dip 21° S. and strike N. 60° E. At Tott Gap in the same quadrangle the Shawangunk dips 80° S. at 1200 feet altitude, but only 55° S. at the gap,—that is, there is evidently overturning.

Doubtless this period of folding also affected the Martinsburg. It probably accentuated much of the folding seen in the slate and developed the curved slaty cleavage planes and false cleavage described in the section on Structural Geology. It may well have caused the greater part of the faulting and almost certainly was related to the bedding slip faults already mentioned.

MESOZOIC AND CENOZOIC ERAS

Post-Paleozoic peneplanation.—Since the Permo-Carboniferous folding, the rocks of this area experienced no deformation of which the record can be read in the preserved structures. The Appalachian Revolution produced mountains which now began to suffer that steady filing away by water and air to which all earth protuberances are inevitably subject. Ultimately an erosion surface was developed on which the rivers, almost at grade, meandered lazily. This was the Kittatinny peneplain, of which remnants are preserved at elevations of 1,400 to 1,600 feet today. It is generally said to date back to Cretaceous or even earlier times,[89] although Shaw would make it of Tertiary age.[90] This peneplain is shown in Plate I, B. Since Davis' first work on this peneplain, several lower levels of erosion have been recognized. Of the most well marked the following may be may be mentioned:

1. Schooley: At altitudes of 1,000 to 1,200 feet; forms benches on sides of Blue Mountain.
2. Honeybrook: At altitudes of 800 to 900 feet; forms lowest benches along Silurian escarpment, and isolated hills in the slate belt.
3. Harrisburg: At altitudes of 760 feet or slightly higher;

[89]Davis, W. M., The geological dates of origin of certain topographic forms of the Atlantic slope of the United States: Geol. Soc. Am., Bull., vol. 2, p. 547, 1891.

[90]Shaw, E. W., Age of the peneplains of the Appalachian province: Geol. Soc. Am., Bull., vol. 29, p. 586, 1918.

forms highest tops, especially in sandy member of the Martinsburg formation.

4. Early Brandywine (Somerville): At 400 to 450 feet; this occurs in the limestone valley.

These figures are modified from those of Bascom[91] to meet the situation in this region. The early Brandywine peneplain is assigned to the Pliocene epoch and the Kittatinny to the Lower Cretaceous by Bascom, the others being given intermediate ages.

Although these erosion cycles are generally accepted, the writer confesses to doubt as to their validity. It is a striking fact that the Somerville peneplain is always developed on limestone, the Harrisburg always on slate. So true is this, that in the Slatington quadrangle Huckleberry Ridge, an outlier of slate in the limestone, rises to the theoretical level of the Harrisburg peneplain out of a limestone valley that consistently equals in altitude the level of the Somerville. Such observations suggest that the rate of erosion in rocks of varying resistance is at least a factor contributing to the accordance of summit levels.

Pleistocene history.—During the Pleistocene epoch the ice came into the region from the north. This direction of advance is recorded in the presence at Tott Gap of striae trending S. 50° E. One mile southeast of Slateford striae are again seen, also, trending south.

The earliest ice sheet advanced as far as Bethlehem, well south of the district here discussed. If this sheet be accepted as of Jerseyan or of Kansan age, following Salisbury, there was a subsequent retreat and a readvance to the morainic front indicated on the areal map. A later retreat ended the Ice Age. With the purely glacial deposits are found those characteristic of the streams that issue from the ice front.

Post-Glacial history.—Since the melting and recession of the ice, rivers have resumed their erosional work. This has resulted in the development of multiple cycles along even such short streams as Martins and Monocacy Creeks. The latter meanders in a wide trough with low banks where it crosses the limestone valley. Farther headward it flows in a youthful valley between steep slate bluffs. At its head again, it drains swampy land of low relief, typical of glaciated territory.

COMPOSITION OF THE SLATE

GENERAL FEATURES

For this study 27 thin sections of slate were prepared and many others were made available through the kindness of officials of the

[91] Bascom, Florence. Cycles of erosion in the Piedmont province of Pennsylvania: Jour. Geol., vol. 29, p. 544, 1921.

United States National Museum. Descriptions of selected sections are given below, to serve as illustrations. Where possible, comparisons are drawn between the compositions of beds resembling each other. Chemical analyses were made by M. K. Buckley of Lehigh University.

Sections were generally cut parallel or at right angles to the cleavage. Of these the former yielded by far the most information as to mineral constituents, while the latter were instrumental in determining the structural relations of the particles. In general the sections parallel to the cleavage planes show basal pinacoids when the minerals have good basal cleavage, so that the constituents could be readily identified.

In sections at right angles to the cleavage, on the other hand, fibres of muscovite and chlorite and grains of quartz and calcite are elongated parallel to the cleavage. Slender strands of chlorite and muscovite run in the cleavage traces and weave in and out among the more granular minerals, such as quartz and calcite.

The minerals observed in the slate include calcite (probably magnesia bearing*), muscovite (sericite), chlorite, quartz, plagioclase, biotite, rutile, pyrite, magnetite, graphite, and zircon. Of these, plagioclase, biotite, pyrite, magnetite and zircon were rarely seen. Kaolin is probably present but could not be positively identified.

The structure and mineral composition of slate has been described in detail by Dale,[92] and to this summary little can here be added.

Conclusions in regard to the primary composition or origin of the clayey sediments from which the slate was derived are incorporated in the section of this report dealing with geologic history. Generalizations as to the metamorphism and sequence of minerals in the slate are included in the section of metamorphism. What follows is mainly a description of the mineralogy and chemical constitution of the various types of slate in the district studied.

HARD SLATE

Slate from the Chapman quarries was microscopically examined in a section parallel to the cleavage. Very few large grains of quartz are in evidence, and much of the groundmass is amorphous or so finely crystalline that under the crossed nicols the brilliantly colored calcite and muscovite stand out sharply from the dense, colorless background. The flakes of mica have an arrangement faintly suggesting fluidal texture. Two bands of darker material, evidently more carbonaceous beds, cross the field, and are separated by a width of

*Hillebrand, W. F., Slate in the United States: U. S. Geol. Survey, Bull. 586, p. 56, 1914.

[92]Dale, T. N., Slate in the United States: U. S. Geol. Survey, Bull. 586, pp. 14-23, 1914.

lighter colored matter; the dark bands differ only in containing a larger number of carbon masses. The light bands consist of:

Muscovite.—In flakes 0.015 mm. in average length. These are generally definitely elongated in one direction, though the more equidimensional pieces are less well oriented. The crystals are partly very narrow and in shreds, but are largely irregular. The shreds are distinctly thinner at the ends, as though corroded. Here and there graphite masses are included in the muscovite. Extinction of many adjacent flakes is frequently parallel; a marked parallelism of the long crystal axes is also noted, and although the grain direction in the thin section is not known, it is thought to be determined by this parallelism.

Quartz.—This occurs in two forms:

1. Pearly, crystalline; largely concealed by an unresolved background of fine needles; inclusions are common.

2. Well crystallized, in many cases actually automorphic (idiomorphic). This is generally free from inclusions.

Carbon.—Always in black, discoidal masses. The disks vary in size from infinitesimal to 0.015 mm. in diameter. Some of the smaller dots combine, so that the closely packed space that bears them has the shape of a leaf.

Calcite.—In rhombs, or in flat, irregular flakes. No twinning is seen. If the grains are large, they locally contain quartz inclusions. Some masses vary up to 0.07 mm. in length. The edges of the calcite grains may be irregular or with sharp, linear boundaries.

Chlorite.—With slight pleochroism, green to white. In more or less lenticular masses, sometimes with parallel, very good cleavage which is generally at right angles to the elongation of the muscovite crystals. These areas strongly resemble in form the feldspar masses described by Dale[93] in Ordovician schists from Dorset, Vermont; in the slate, however, they are chloritized mica, not feldspar. The lenses mentioned occupy areas suggesting crystalloblastic origin, but the adjacent minerals give no evidence of having been thrust aside by chloritization. There has apparently been some movement later than their formation, as the cleavage is frequently curved. In places muscovite, paralleling the chloritic cleavage perfectly in its elongation, is still preserved in the chlorite masses.

Rutile.—In tiny needles, generally about .009 mm. long, and showing a tendency to have their longer axes directed parallel with those of the muscovite shreds.

Plagioclase.—A few grains are seen, showing twinning according to the albite law. They are largely concealed by other material.

SOFT SLATE

Typical slate of the big beds.—A section of the Genuine big bed, made from a specimen collected from the Albion quarry at Pen Argyl, was examined. The section shows exceptionally uniform size of the grains, a feature which may well account for the perfect cleavage and excellent grade of the slate as electrical material. The section parallel to the cleavage exhibits medium-sized grains of calcite, quartz, muscovite, and chlorite in a rather dense groundmass, not resolvable into its constituents even with strong lenses. The slate is darkened by the presence of rutile needles and of graphite. Its composition is approximately muscovite 20 per cent, chlorite 20, calcite 15, quartz 10,

[93]Dale, T. N., Structural details in the Green Mountain region and in eastern New York: U. S. Geol. Survey, Bull. 195, pp. 16-17, 1902.

groundmass and minor constituents 35. Detailed examination yielded the following observations:

Muscovite.—Occurs in three forms: in rounded, irregular masses 0.015 mm. or less in diameter; in fibres up to 0.03 mm. long and very slender; in shreds or borders associated with masses of chlorite. The crystals show no definite parallelism.

Chlorite.—In grains, round or elliptical in form. Some of the grains are very large, one measuring 0.12 by 0.03 mm. The cleavage in the chlorite is well developed and muscovite is not uncommonly associated, as though the chlorite were derived from the mica. The chlorite cleavage trends in any direction; in places it is crossed by masses of magnetite.

Calcite.—Occurs in small rhombs or masses 0.015 mm. in diameter.

Quartz.—Generally in clear, equidimensional grains, varying in size up to 0.025 mm. in diameter. The inclusions are largely rutile.

Graphite.—In rounded masses 0.015 mm. or less in diameter.

Magnetite.—In angular grains, generally in the chlorite.

Rutile.—In small needles, largely as inclusions.

A section representing a thick bed at the New Diamond quarry, cut parallel to the cleavage, was examined. The slate differs but little from that of the Genuine big bed as described above. The distinction lies chiefly in the greater size of the quartz, calcite, and chlorite grains in the latter, and in the less uniform distribution of these larger crystals in the groundmass. The muscovite grains are distinctly larger. Quartz frequently shows irregular and embayed boundaries against the calcite, as though one mineral were in progress of being replaced by the other; it is not clear, however, which is the original mineral.

In sections of the same bed, cut at right angles to the cleavage, the same type of quartz—calcite relations are seen. The sections parallel to the grain plane show exceptionally long lenses of quartz. Sections at right angles to both grain and cleavage planes, exhibit crystalline masses of quartz and calcite; the chlorite areas are less highly attenuated than in sections parallel with the grain. It is also noted that there are many small, round inclusions in the larger minerals; these are largely rutile needles, viewed parallel to their long axes.

Bangor and Pen Argyl beds compared.—It is said by the quarrymen that the Bangor beds are "tougher" and "stronger" than those of Pen Argyl. In the hope that the explanation could be found for this difference, beds in which the textures are comparable in fineness were selected from the Bangor and Pen Argyl groups and thin sections of these compared under the microscope. In general, the impression conveyed is that the Pen Argyl beds are somewhat coarser in texture and that they contain a very slightly greater quantity of chlorite, but microscopic measurements are not sufficiently accurate to sustain the latter statement and both conclusions may well have been induced by the beds selected. Contrary to what was expected, there is no evidence

of a larger quantity of quartz in the Bangor beds, either in the analysis or in thin sections. In all respects the statement can be made that mineralogically and chemically the composition of the Bangor beds does not differ appreciably from that of the Pen Argyl beds.

Harder and softer beds compared.—At the Consolidated No. 1—Star quarry, two specimens were selected by the quarrymen to compare a very soft with a very hard bed in the slate. Microscopic study of sections parallel to the cleavage showed that the soft slate differed from the harder in the following:

1. The chloritic and muscovitic bands along which the slate cleaves are more closely spaced in the softer slate.
2. The individual grains are smaller in the soft slate than in the harder slate.
3. The total volume of quartz in proportion to the other constituents is less and that of chlorite and calcite more in the softer slate.

A similar question was faced by Dale,[94] who concluded, from studies in the slate belt of Vermont, that the relative "softness" of some slates was to be attributed to their greater percentage of carbonate and to the smaller size of the individual quartz grains, rather than to the lower percentage of silica.

A chemical analysis of each of these two specimens was made.

Chemical analyses of slate from Consolidated No. 1-Star Quarry.

[M. K. Buckley, analyst.]

	Exceptionally hard slate	*Exceptionally soft slate*	*Lehigh**
SiO_2	57.14	55.56	56.38
Fe_2O_3	5.76	6.18	4.90
Al_2O_3	17.08	20.57	15.27
CaO	3.95	3.27	4.23
MgO	3.29	2.76	2.84
K_2O	3.11	2.95	3.51
Na_2O	1.05	1.12	1.35
Loss on ignition	9.75	9.50	8.35
S	0.82	1.84	0.92
TiO_2	0.53	0.66	0.78
	102.48	104.41	98.53

[94]Dale, T. N., The slate belt of eastern New York and western Vermont: U. S. Geol. Survey, 19th Ann. Report, part III, p. 245, 1899.

*Analysis of typical slate from Lehigh Co., Pa., for comparison; see Dale, T. N., Slate in the United States: U. S. Geol. Survey, Bull, 586, p. 51, 1914.

Between the two analyses the conspicuous difference is the higher silica content of the harder slate.

"Ribbons."—A dark "ribbon" from the Albion quarry was examined under the microscope in a section parallel to the cleavage. The texture is coarsely granular, the larger grains consisting of quartz, calcite, and muscovite. The composition is roughly: graphite 35 per cent, calcite 25, muscovite 20, quartz 10, and groundmass 10 per cent. Graphite is very common and largely obscures the field. Chlorite is not conspicuous. The darker slate in this section is crossed by a band 0.12 mm. wide, consisting of very small particles rarely exceeding 0.005 mm. in diameter and closely packed, apparently mainly muscovite and calcite, with occasional quartz grains. The larger part, by far, of the slate is very dark and shows the following constituents:

Calcite.—In well-formed rhombs or irregular flakes, which vary in size up to 0.09 by 0.025 mm. No twinning is to be seen. The perfect rhombic shape of some of the masses is typical. Rutile inclusions in the calcite are common.

Muscovite.—In irregular flakes, generally somewhat oblong, with the longer axes roughly parallel, but not as distinctly so as in the hard slate; more rarely it occurs in long fibers. Dimensions vary up to 0.045 by 0.030 mm. Much is in very small particles. Simultaneous ("aggregate") extinction is poorly defined.

Quartz.—In all sizes, mostly in flakes about 0.015 mm. in diameter; generally clear and free from inclusions except rutile needles. Some grains are as much as 0.05 mm. long, but in this case the shape is frequently slender.

Graphite.—In rounded masses up to 0.01 mm. in diameter. Graphite also occurs as angular, irregular inclusions in chlorite.

Chlorite.—In rounded or elliptical grains, frequently showing well developed cleavage. The sizes of the grains are similar to those of the quartz. Graphite and magnetite inclusions are present.

Biotite.—Rare.

Pyrite.—In stringers and irregular masses as inclusions, mainly in the chlorite.

Magnetite.—In tiny grains, included in the chlorite.

Rutile.—Numerous very small needles, largely inclusions, and generally with their longer axes parallel.

The description may be regarded as typical of all the "ribbons" of the soft slate examined. In sections inclined to the bedding, the lines separating alternating darker and lighter bands are very well marked. The bedding frequently is jagged and irregular, and small lenses of carbonaceous matter lie between less graphitic laminae.

A chemical analysis of the ribboned slate described above follows.

Analysis of "ribbon" from Albion quarry, Pen Argyl.

[M. K. Buckley, analyst.]

SiO_2	54.56	K_2O	3.12
Fe_2O_3	7.15	Na_2O	1.96
Al_2O_3	16.47	Loss on ignition	6.76
CaO	4.46	S	0.87
MgO	2.90	TiO_2	0.83

In interpreting this analysis, the low quartz, the rather low chlorite, and the high calcite contents as shown in the section, should be borne in mind. The apparently large number of rutile needles is corroborated by the high value of titanium oxide obtained. The amount of carbon present cannot be determined with certainty from the analysis as given. There appears to be an abnormally large amount of sulphur; pyrite in quantities is a common feature in the darker slate, according to Dale,[95] but this mineral appears to be rare in the thin sections examined.

The Gray beds.—There are two Gray beds in the soft belt, one in the Pen Argyl beds and one in the Bangor group.

A thin section of a specimen obtained from the Albion quarry and cut parallel to the cleavage was examined. The slate is exceptionally free of dark material, containing graphitic spherules in small quantity only. The texture is even and fine. The main constituents are present in approximately the following per cents: groundmass of chlorite and muscovite, 60; calcite (magnesia bearing), 15; quartz, 10; muscovite in flakes, distinct from the fibrous groundmass, 5; chlorite in large pieces, distinct from the groundmass, 5; minor constituents, 5. Examined in detail, the section shows:

CALCITE: In poorly formed rhombs, measuring up to 0.09 mm. in width. These rhombs show little corrosion. There are also irregular masses, all small. A crystal of highly altered plagioclase was seen, partly replaced by calcite, but still showing twinning.

QUARTZ: This is in small grains which do not stand out clearly from the groundmass. In size they vary up to 0.05 mm. The crystals show no strain effects. Rutile inclusions are common.

MUSCOVITE: In three forms:

1. In masses, consisting of fibres placed side by side; the separate shreds or fibres show simultaneous extinction; such masses vary up to 0.045 mm. in diameter.

2. In thin fibres, separate and with simultaneous extinction for the most part. Such shreds are very slender and in length extend to 0.03 mm. They are intermingled with the similarly arranged, but far more numerous chlorite fibres.

3. Shreds, less slender than those last described but having about the same length. They are not elongated with the grain direction, but lie irregularly across the latter.

CHLORITE: In two forms:

1. In masses, more or less rectangular, up to 0.2 mm. in magnitude. The

[95] Op. cit., p. 52.

chlorite is fibrous, the fibres generally elongated at right angles to the length of the crystals in the groundmass of the slate, and hence normal to the grain direction. The chlorite is pleochroic, showing faint pine green to very light straw-color. Some of the fibres in these masses are mica and have high interference colors; not uncommonly they are faintly brownish and show good pleochroism, suggesting that they are the remaining strands of otherwise highly chloritized biotite.

2. In isolated fibres, scattered throughout the groundmass, parallel to the similarly arranged muscovite crystals.

GRAPHITE: Mostly in round spots up to 0.01 mm. in diameter, here isolated, there matted together into lenticular masses; in the latter case, the individual grains are generally very small. Irregular masses, angular pieces, and tiny stringers of graphite are also seen.

RUTILE: In the usual small needles.

A specimen of the same Gray bed was collected in the Tinsman quarry. A section at right angles to the cleavage was examined with the microscope. In this section quartz is much more in evidence. It is lenticular and bears small bubble-like inclusions. Where it abuts against chlorite or muscovite strands the latter project into embayments in the quartz; moreover, the quartz shows no strain figures. It is evident, therefore, that much of it at least does not antedate in origin the deformation that sericitized the slate. In places, irregular masses of calcite lie partly enclosed by the quartz, but it is not clear which is the earlier mineral. Some quartz, clearly antedating the sericitization of the slate, has been broken, probably by the deformation accompanying the development of cleavage, and now forms granular stringers in the rock.

It is clear, in this section at least, that the large, rectangular masses of chlorite are actually altered biotite. Their pleochroism, the rare preservation of fibres of biotite, and the presence of small masses of iron oxide, not seen in the section parallel to the cleavage, leave no doubt as to the correctness of this interpretation. The longest dimensions of the fibres in these areas of chloritized biotite generally lie inclined to the cleavage. An average of fifteen observations gave 28° as the angle between the elongation of these fibres and the cleavage trace in the vertical (or grain) plane.

A thin section of the Gray bed of the Bangor group shows marked differences from that just described. Quartz is in evidence and, though clear, without strain shadows, and uncorroded, shows much fracturing. Calcite is far more common than in the Gray bed of the Pen Argyl group. Chlorite appears in large pieces in two forms, (1) the fibrous type previously noted and (2) large flakes, rather clear but with inclusions of rutile needles in triangular groups; the latter phase of chlorite is greenish in color, and apparently represents sections cut in the basal plane. Slightly more carbon is seen in the Bangor Gray bed than in that of the Pen Argyl group.

Chemical analyses of Gray beds.

[M. K. Buckley, analyst.]

	Pen Argyl	*Bangor*
SiO_2	64.52	59.67
Fe_2O_3	4.31	4.24
Al_2O_3	16.84	21.97
CaO	2.21	1.18
MgO	2.94	3.46
K_2O	3.42	2.83
Na_2O	1.76	0.91
Loss on ignition	4.37	9.73
S	0.35	0.23
TiO_2	0.49	0.40
	101.21	104 62

Noteworthy in these analyses are the high silica and the low iron, calcium, sulphur, and titanium contents. A part of the silica is unquestionably accounted for by the relatively large amount of chlorite and the small quantity of carbonates present.

Siliceous beds or "hard rolls".—A section from a "hard roll" in a Pen Argyl quarry is described below as typical of the petrography of such beds. The section is cut parallel to the cleavage. The texture is very coarsely granular in comparison with true slate, and shows what might be described as an arkosic quartzite rich in calcite, chlorite, and sericite. Rutile is conspicuously absent. Most of the definitely recognizable grains are 0.05 mm. or more in diameter. The approximate proportions of the constituents, as measured by a modified Rosiwal method, is quartz 30 per cent, calcite 25, graphite 15, chlorite 10, muscovite 10, feldspar 5, other constituents 5. From this list the dominance of granular minerals, as opposed to those possessing a definite axial elongation in one or more directions, is at once apparent. A detailed description of the minerals in the section follows:

QUARTZ: Of two types:

1. Showing strain shadows; inclusions are present in many cases. Calcite is commonly developed along the fractures. Quartz grains of this type have rounded, but clear outlines.

2. In masses that are clear, but show fracturing. Strain shadows are rare. This quartz frequently fringes out at its edges, taking in intergrowths, which, insofar as they can be resolved, consist of filaments of chlorite and quartz with rare muscovite (sericite).

The grains of quartz vary up to 0.08 mm. in diameter.

CALCITE: Frequently in irregular masses cutting across chlorite fibres; or in poorly defined rhombs; or forming projecting embayments into corroded quartz or feldspar. It appears to be later than much of the quartz. One rhombohedron was seen in the center of a mass of chlorite, showing it to be even later than that mineral.

GRAPHITE: In thin amorphous blotches, apparently mixed with limonite, or pure and in smaller, spherical dots. With the low-power objectives, all of the graphite blotches appear to be drawn out in one definite direction, probably that of the grain. Rarely lenses of a mixture of quartz and graphite occur.

MUSCOVITE: This forms more or less fibrous masses or flakes, scattered through the rock. Occasionally it makes up lenses like those mentioned below under chlorite, but not yet altered to the latter mineral. It also forms fibrous intergrowths with quartz and chlorite, especially along the borders of large quartz crystals; in these intergrowths, all minerals have their longer dimensions parallel.

CHLORITE: In many cases taking a part in the intergrowths, just as do quartz and muscovite. Elsewhere the chlorite forms a network of acicular masses, inconspicuous because of low birefringence, the greater elongation of which corresponds with the grain direction. Finally, the chlorite occurs in lenses, with cleavage well developed and more or less at right angles to the grain direction. Wherever its origin is clear, the mineral appears to be secondary after mica.

FELDSPAR: Some oligoclase grains were seen, very little altered or decayed. They vary up to 0.12 by 0.66 mm. in size. The crystals are remarkably uncorroded.

BIOTITE: One piece showing tawny color and high pleochroism. Highly chloritized.

PYRITE: As spherules, commonly in centers of chloritic lenses. Rare.

ZIRCON: Well rounded, but still giving some indication of its original form.

Sections cut (1) at right angles to cleavage and parallel to the grain and (2) normal to both cleavage and grain were also examined. In these the strain shadows in the quartz are again well shown, and the importance of the chlorite as a major constituent is emphasized. The parallelism of the chlorite, so perfect in the section in the plane of the grain, is not nearly as well marked in the section at right angles to grain and cleavage. There is also a distinct tendency for quartz crystals to be elongated in the grain plane; in the section normal to grain and cleavage this tendency is less marked.

Electrical slate.—A section of electrical slate from the Albion "run" at Pen Argyl was studied under the microscope. The conspicuous features in electrical slate are the fineness of the texture and the uniformity in the sizes of the individual grains. In sections examined, no single crystal or fragment showed a diameter of over 0.1 mm. The average size is about 0.015 mm. and quartz, which forms the largest areas, becomes very conspicuous in the surrounding fine groundmass, even if it only measures as much as 0.03 mm. in diameter. Indeed, the quartz rarely exceeds 0.06 mm. in any dimension. Single graphite spherules attain a diameter of 0.09mm; aggregates of carbon may become twice as large at most, but this extreme in size is rare.

The texture of the typical electrical slate may well be compared with that of other workable slates of the soft belt. The electrical slate is distinctly finer and more uniform in size of grains than one of the large beds of the Diamond "run" and than either the Gray bed of the Bangor group or that at Pen Argyl. Of the slides examined, the Genuine big bed of the Albion "run" alone seemed to possess equal qualities of fineness and uniformity of texture.

The fine-grained groundmass in the electrical material is resolved into its components with difficulty, even with a strong lens combination. Conspicuous minerals are calcite, chlorite, quartz, muscovite, and graphite; estimates indicate that the relative quantity is in the order named. No iron compounds other than clouds of limonite were seen in the rock.

It appears, therefore, that the three essential qualities of an electrical slate, as to mineral content, are:

1. Uniformity in size of crystal particles.
2. Fine texture.
3. Absence of deleterious minerals; these are magnetite, hematite, pyrite, and graphite.

The chemical composition of electrical slate is distinct from that of other slates in only one particular, and that is the low iron content. In the reduced quantity of iron oxide present ideal electrical slate is rivalled only by the green, chloritic slate of the Bangor and Pen Argyl Gray beds. Two analyses follow.

Analyses of electrical slate from Pen Argyl beds.

	1	2
SiO_2	57.50	55.32
Al_2O_3	20.84	20.01
Fe_2O_3 and FeO	3.51	5.13
CaO	3.92	2.21
MgO	3.02	3.63
K_2O	3.36	3.67
Na_2O	1.25	1.84
CO_2	3.30	Not recorded
Loss on ignition	.15	6.85
Pyrite	1.39	Not recorded
S	Not recorded	0.76
C	0.57	Not recorded
TiO_2	Not recorded	0.99

1. Electrical slate from Structural Slate Co., Pen Argyl; N. V. Anderson, Lehigh University, analyst.

2. Electrical slate from Stephen Jackson Co., Albion quarry, Pen Argyl, M. K. Buckley, analyst.

In both cases the iron oxide content is less than 5.25 per cent. It would be higher than 3.51 per cent in analysis 1, if the iron present in the pyrite were assigned to its position as oxide. The low carbon content of good electrical slate is well shown in analysis 1; carbon is included under "Loss by ignition" in analysis 2.

Blackboard slate.—A section at right angles to the cleavage shows little that is distinctive except the rather high content of cloudy carbon masses. There is suggestion also of somewhat more than the usual

amount of calcite. The quartz is generally granulated or shows strain shadows. Sericite and chlorite are well oriented.

Individual pyrite spherules averaging about 0.003 mm. in diameter, but reaching as much as 0.03 mm., are common. Aggregates of carbon, generally composed mainly of small granules or clouds, attain areas as much as 0.15 mm. square; these are generally lenticular, the longer dimensions being parallel with the cleavage.

Siliceous knots.—These spots or blotches, generally rounded or lenticular, but frequently irregularly bounded, show in the rough hand specimen as areas where the surface is irregular and the cleavage poor. With low magnifications of the microscope they prove to be composed of many closely-packed quartz grains of about the same size as in other slate; these areas are fairly free from carbon, except in thin stringers. They are bordered, however, by typical slate, with carbon conspicuously present. The boundary between the quartz-rich, carbon-free "knot" and the typical slate is generally sharp.

These siliceous knots may be explained in one of three ways:

1. The knot may be an area where the quartz grains were fortuitously aggregated by irregularities in sedimentation.
2. Each knot may represent an individual quartz pebble or grain laid down during sedimentation, subsequently badly granulated and sheared into many fragments.
3. The knot may be attributed to secondary silicification, its location being due to some especially favorable chemical factor.

The first of these explanations seems most acceptable because:

1. The excessive granulation called for by hypothesis 2 would yet leave a trace of a markedly larger piece of the original pebble and would scarcely comminute the ancestral pebble or grain into particles of so uniform a size.
2. Hypothesis 3 calls for recent silicification with probably little or no subsequent change in the quartz. Yet many of the grains are severely corroded and partially replaced by calcite, while others show the irregular optical extinction of strained quartz and thus indicate that they have been deformed, probably in the time interval during which the slate was also undergoing sericitization.

Hypothesis 1 thus remains the only acceptable one and, taken in conjunction with other minor irregularities in deposition, is in complete agreement with the facts observed.

ECONOMIC GEOLOGY OF THE SLATE

GENERAL SUMMARY

DELETERIOUS FEATURES.

Various geologic features are deleterious to slate quarrying in parts of the region studied. These may be briefly summarized.

A heavy overburden, either of unconsolidated glacial till or river deposits or of partially disintegrated slate, makes stripping operations prohibitively expensive. The overburden is discussed below under "Effect of Physiographic Features."

Any irregularities in the character or sequence of the beds are generally unfavorable to quarry operations. Thus ribbons and hard rolls (page 103) are frequently objectionable, though not always seriously so. Siliceous knots and graphitic flakes (page 103) are deleterious.

Certain irregularities in the attitude of bedding or of cleavage are undesirable. In general, gently dipping beds are less suited to quarrying than vertical ones. Curved cleavage (page 109) and false cleavage (page 110) are serious disadvantages.

Faulting of all sorts (page 113) is harmful. Closely spaced joints, especially when intersecting the grain at other than right angles, are troublesome in quarrying (see page 113).

Finally, excessive quarry water necessitates costly pumping and introduces other dangers (see page 115), though a moderate amount prevents the slate from becoming brittle.

THE IDEAL SLATE QUARRY.

The conditions most favorable to successful slate quarrying, on the other hand, are pictured below. An ideal quarry should have but little overburden of glacial material, river deposits, or disintegrated slate. It should be supplied with a moderate amount of water. If the opening is in the soft belt, there should be few or no siliceous ribbons and no knots or carbonaceous flakes. The strata should be nearly vertical and with a constant dip. Faults should be lacking. Ideally the beds should strike at right angles to the grain and parallel with the cleavage. Jointing should be regular and of one system, the strike being parallel with that of the beds and the dip forming a vertical angle of 90° with the bedding dip.

EFFECT OF PHYSIOGRAPHIC FEATURES

DELETERIOUS EFFECTS

The presence of a thick glacial cover makes the cost of quarrying prohibitive in much of the district. As has been indicated in the section on the Quaternary System, there is a heavy glacial overbur-

den in parts of the region mapped. This overburden is thin in the belt underlain by the middle, sandy member of the Martinsburg formation and generally equally so in the hard belt. It will be recalled that the hilly region marking the outcrop of the middle member extends westward from Slateford on Delaware River through Johnsonville, Bangor, Delabole, Grand Central, Knechts, Schall School, Point Phillip, and St. Joseph School. These localities mark the northern edge of the broad belt of country underlain by the middle, sandy member. Northward from the line thus defined, therefore, the region is largely covered with glacial deposits.

As already stated, a marked belt of terminal moraine can be recognized, beginning half a mile northwest of Delabole and extending thence southward through Ackermanville, Factoryville, Nazareth Junction, Mount Pleasant, and the mouth of Oughoughton Creek. The southwestern boundary of this moraine is indicated on the map, and the width of the deposits is about one mile. The heavy cover of glacial and outwash material here again precludes easy exploration for slate.

Finally the entire soft slate belt from Bangor eastward is heavily covered with deposits of mixed terminal and ground moraine, so that quarries are not readily opened here.

These glacial and glacio-fluviatile deposits are variable in depth, but are always a hindrance. At Slatefield they have a thickness of 5 feet. At Delps and along the railroad eastward their thickness is at least 8 feet. In the walls of the Albion Bangor quarry 50 feet of drift are exposed; and in the Tinsman quarry, 15 or more feet. At Wind Gap the drift thins again, as shown in the Phoenix quarry, but at Alpha it attains a thickness of at least 15 feet, in the Albion Superior quarry. There is another thinning at West Pen Argyl, but the Jackson Bangor quarries, especially the southern ones, the Delabole quarry, and all of the quarries at Bangor bear much overburden.

As the southern flank of Blue Mountain is approached, the talus from its quartzite cliffs is added to the overburden of glacial and glacio-fluviatile material. In fact, this heavy cover of huge blocks is an insurmountable obstacle and prohibits the opening of quarries within two thousand feet of the probable contact between the Shawangunk conglomerate and the Martinsburg formation, even though the concealed uppermost strata of the Martinsburg are very probably, in part, good slate.

Where these different types of overburden, either singly or collectively, attain an appreciable thickness, they either totally forbid or at least seriously hamper the development of slate quarries. In general, this deleterious effect is felt when the overburden exceeds ten feet. In all cases where much overburden is present, cribbing must

be resorted to and the surface must be stripped back some distance from the edge of the opening to prevent boulders from falling down the walls into the hole. When the opening is widened, steam shovels are generally used to lay bare more of the surface slate, and space must be provided to accommodate the sand, clay, and boulders thus removed.

BENEFICIAL EFFECTS

The overburden has one beneficient effect. Glaciation itself must have stripped off most of the waste slate formed by weathering between the time of first uplift above the Paleozoic sea and the advance of the ice sheet. Upon the relatively fresh surface thus exposed the ice-borne deposits were then laid down. Most of the decay now seen at the surface of quarries took place since the retreat of the ice, and the presence of ice-laid or water-laid material has retarded the weathering of the underlying slate. When the burden is stripped, therefore, less waste slate need be taken out before usable material is found. This is partly because the oxidizing power of downward-moving solutions is spent on the surface material before the slate rock is reached, and partly because rapid expansion and contraction of the rock with changes in temperature, the expansion of freezing water in cracks, and similar climatic effects are reduced or even nullified under the insulating blanket of the glacial or glacio-fluviatile overburden.

EFFECT OF TOPOGRAPHY

The slate is very often laid bare where streams have cut deep channels. Such exposures facilitate correlation of individual beds and frequently enable the quarryman to select an ideal site for the opening.

Where the slate lies on a slope and the cleavage is nearly vertical the creep of the superficial layers down the hill may produce distortion of the cleavage planes; in such cases, when the exposure is on the south side of a hill, the dip of the cleavage, which is generally already to the south, is greatly increased or the cleavage is even overturned so that the planes actually incline northward instead of southward. This phenomenon has also been attributed to the drag of the southward moving ice sheet.[96] It is well seen in the Acme quarry on the eastern wall, and is a common feature in the slate region.

EFFECT OF STRATIGRAPHIC FEATURES

HARD SLATE

Description.—Hard slate consists of strata which are either highly silicious, unusually carbonaceous, or more purely sericitic than usual. The megascopic features have already been described. For a microscopic description, see the section on the composition of the slate.

[96]Dale, T. N., Slate in the United States: U. S. Geol. Survey, Bull. 586, Plate XVII, 1914.

The hard slate splits well except where the cleavage plane crosses one of the rare wider ribbons of siliceous material. The cleavage surface, however, is nowhere as smooth as in the soft slate. Locally the cleavage planes are somewhat curved for long distances.

The siliceous ribbons or beds wear well, and do not decay as do the carbonaceous beds of the soft slate; in fact, they appear to be the more resistant part of the hard belt slate.

"Flint or spar".—The hard, sandy beds abrade the tools greatly. In places, masses of quartz and, more rarely, calcite, were deposited, either parallel to the cleavage or in small, gash-like joints not over a foot long. Such masses are spoken of as "flint" or "spar" by the quarrymen. They interfere with perfect cleavage and wear the cutting edges of the tools.

Uses.—This slate is of use for roofing only. It was once made into blackboards, with the aid of diamond dust and diamond saws, but this method of polishing was expensive and the siliceous layers gave the slate a banded appearance. Hence for this purpose soft slate has replaced the hard. The repeated alternation of the beds prevents the use of even the smaller fragments for electric insulation, as the ohmic resistance varies greatly within a small block.

SLATE IN THE MIDDLE MEMBER

Description.—The lenses of slate mentioned as occurring in the sandy member have been opened in only two places, the Batt quarry, about two miles south of Wind Gap post office, and a small quarry now covered, about one mile west of Johnsonville. The slate mined was seen only at the Batt quarry. Here it is closely ribboned, resembling that of the hard belt, but the siliceous laminæ are less common, and the beds have a distinctly "papery" weathering. The weathered surface rises from the bed rock in layers 0.1 inch or less thick and finally breaks off to form thin scales. This characteristic, although not limited to the horizon, is more typical of soft belt slate. Its possession by the slate lenses described places them intermediate in character between the soft and hard slates.

No thin sections of the slate were examined.

Uses.—The slate was used wholly for roofing. It is now no longer quarried.

SOFT SLATE

Description of the slate.—The valuable part of this member consists of alternate beds of highly carbonaceous dark blue-gray and lighter colored, more purely sericitic material. Rare beds of almost wholly chloritic slate and occasional very thin calcareous layers are also present, but form an almost negligible portion of the total valu-

able thickness. For a description of thin sections, the part of this report dealing with the composition of the slate should be consulted.

"Ribbons."—The "ribbons," or thin, carbonaceous beds, have an important bearing on the value of the slate. For millstock, where certain decorative effects are desired, the "ribboned" slate is looked on with favor. For most other uses, slate free from ribbons is preferred. This is because of the following facts: (1) the "ribbons" disintegrate slightly, as is well seen in the slate paving blocks on the streets of Bangor; (2) because of their carbon content, the "ribbons" permit the leakage of electricity; hence "ribboned" slate does not act as a good electric insulator; (3) as the "ribbons" form dark streaks they prevent the use of the slate where a unicolored surface is desired.

"Hard rolls."—The sandy lower parts or "hard rolls" of the thickest beds are generally discarded. They are undesirable for two reasons: (1) they resist the steel in trimming and (2) the cleavage is not plane where it crosses such layers, but possesses a more or less gentle curve, convex upward, so that roofing slate made from such material is curved.

Recently, it is said, these sandy parts of beds have been employed with some success for switchboards and other electric insulators.

Siliceous knots.—Through variations in primary deposition or through secondary segregation of silica, "knots" or patches of quartz occur in some parts of the slate beds. These are irregularly shaped masses, generally approximately circular but not uncommonly lenticular, measuring in diameter two inches or less, and frequently connected with each other by thin stringers of similar matter. A description of their microscopic appearance is given in the section on petrography. Such knots, like other irregularities in composition, introduce variations in resistance and are deleterious if the slate is to be used for electrical purposes. Further, where the cleavage crosses them, an irregular surface is produced. For these reasons knotty slate is to be avoided.

Graphitic flakes.—Not uncommonly a thick bed of clear slate, with the light gray color characteristic of good electrical material, shows irregular masses or flakes of carbon such as have been described in the section on stratigraphy. These carbon flakes also permit electrical leakage, as was demonstrated by Robert Notvest of the Structural Service Bureau. Notvest found that the carbon particles, acting with the ferric oxide (more probably magnetite?) in the slate, form small condensers which facilitate leakage. Several specimens, some with high, others with low carbon content, were tested, and, with 2,500 volts, an average of 441 milliamperes leakage was measured in six specimens containing 1.7 to 2.3 per cent carbon, while three specimens

bearing only 0.6 to 1 per cent carbon gave an average of 148 milliamperes.[97] In the case of Pennsylvania slates, Notvest has reached the conclusion that leakage not attributable to moisture is due to the existence of "an excess content of carbonaceous substances."[98]

Stratigraphic sequence.—It has already been pointed out that the upper member of the Martinsburg formation can be separated into two parts, which, following the quarrymen, may be called the Bangor beds (below) and the Pen Argyl beds (above). Although the exact thickness of the entire series of Bangor or of Pen Argyl beds is not determined with certainty because a complete section across either division is not afforded and because the crumpling of the beds is too severe, exact measurements were made of parts of these smaller stratigraphic divisions as exposed in quarries. In all cases the strata were measured in parts of an inch, the rule being laid along the cleavage; the values obtained were then recalculated to yield actual thicknesses, as measured at right angles to the bedding planes. The results of these observations are shown on the charts (Plate XII and XIII) in pocket.

It will be noted from these charts that certain beds, called "big beds" by the quarrymen, are exceptionally thick. Where such beds can be identified and correlated, they serve as key horizons. In this way, generalized values of the thickness of slate intervening between two beds can be ascertained, whenever that thickness is exposed in the quarries. It should be understood, however; that the resulting values vary sharply with the structural position of the section measured. For example, the beds in the trough of a syncline are far thicker than those on the limbs. The table which follows is therefore generalized.

Within the Bangor and Pen Argyl beds it is customary among the slate operators to recognize large subdivisions called "runs," which include the several beds of slate exposed in a quarry or group of quarries. Although these subdivisions are of a sort standing intermediate between beds and the larger stratigraphic units generally recognized by geologists, the economic value of accepting the terminology of those most concerned with the succession of beds in the soft slate is evident and justifies the retention of the term "run," together with the classification built up by the quarrymen. There are disagreements as to the names applied to some of the runs and to their subdivisions, the separate beds, but the most generally accepted terms have been used in the following table.

In this table the figures given represent average thicknesses in feet. Parts of the sequence were measured in detail, others were only estimated.

[97] Slate for electrical uses: The Structural Slate Co., Pen Argyl, Pa., 29, 1923.
[98] Op. cit., p. 28.

Table of Soft Slate Beds

Pen Argyl beds

Varying thickness to top of upper member of Martinsburg formation as exposed.

		Feet
Pennsylania "run"	Intervening beds ..	21
	Big bed	12.5
	Intervening beds ...	110

Unmeasured thickness, including the United States "run"

Diamond "run"	Johnny Knack bed	10
	Intervening beds ..	46.5
	Genuine big bed ..	6
	Intervening beds ..	5
	Red bed	9
	Intervening beds ..	56.5
	Big bed	7.5

Intervening beds 255

Albion "run"	Jenny Weeks bed ..	10.5
	Intervening beds ..	33.5
	Hard big bed	12
	Intervening beds ..	3
	Big bed	7.5
	Intervening beds ..	72.5
	Gray bed	5.5
	Intervening beds ..	14.5
	Genuine big bed ..	14
	Intervening beds ..	3
	Hard Front big bed	8

Intervening beds 76

Acme "run"	Big bed	6
	Intervening beds ..	41.5
	Big bed	5.5
	Intervening beds ..	27.5
	Big bed	11.5
	Intervening beds ..	5.5
	Big bed	9

Intervening beds 283

Phoenix "run"	Big bed	4.5
	Intervening beds ..	12
	Big bed	5.5
	Intervening beds ..	27.5
	Big bed	4

Bangor beds	Unmeasured thickness, largely sandy beds,		
	North Bangor No 3 "run"	North Bangor No. 3 First big bed	12
		Intervening beds	23
		North Bangor No. 3 Second big bed	11
		Intervening beds	49
	North Banor No. 2 "run"	North Bangor No. 2 big bed	6
		Intervening beds	50
	North Bangor "run"	North Banger big bed	7
		Intervening beds	60
		Mike Taylor big bed	8
		Intervening beds	141
	Bangor Union "run"	Bangor Union big bed	8
		Intervening beds	75
		Black Ribbon big bed	5
		Intervening beds	36
	Old Bangor "run"	13 big bed	5
		Intrevening beds	52
		Gray bed	7
		Intervening beds	22
		Middle (Gray Bed) big bed	7
		Intervening beds	25
		9-foot big bed	3
		Intervening beds	25
	Grand Central "run"	Grand Central First big bed	4
		Intervening beds	25
		Grand Central Second big bed	8

In the above table, beds not included in definite "runs" in mapping are set into the second column, under the caption "Intervening beds". These are generally not exposed and their thickness has been estimated, not accurately measured.

On the geologic maps (Plates II and XIV), the two major divisions of the soft slate, the Pen Argyl and Bangor beds, are separated. For

economic purposes, however, any lines of division that can be recognized within these larger units are of value. By detailed work, it has been possible to trace the productive part of the Diamond "run" and the Albion "run" in the Pen Argyl beds. Similarly, the outcrop of the Gray bed of the Bangor run can be mapped from Wind Gap to Bangor. On the geologic maps of Wind Gap, Pen Argyl, and environs and of Bangor and environs these distinguishable beds have therefore been indicated by separating both the Albion and Diamond "runs" from the rest of the Pen Argyl beds, as far as possible, and by using the line of outcrop of the Bangor Gray bed to divide the Bangor beds into two parts. Of these latter, the upper portion of the Bangor beds includes the North Bangor No. 3, North Bangor No. 2, North Bangor, and Bangor Union "runs", and that part of the Old Bangor "run" that lies above the Gray bed; the lower part includes the remainder of the Old Bangor "run" and the Grand Central "run."

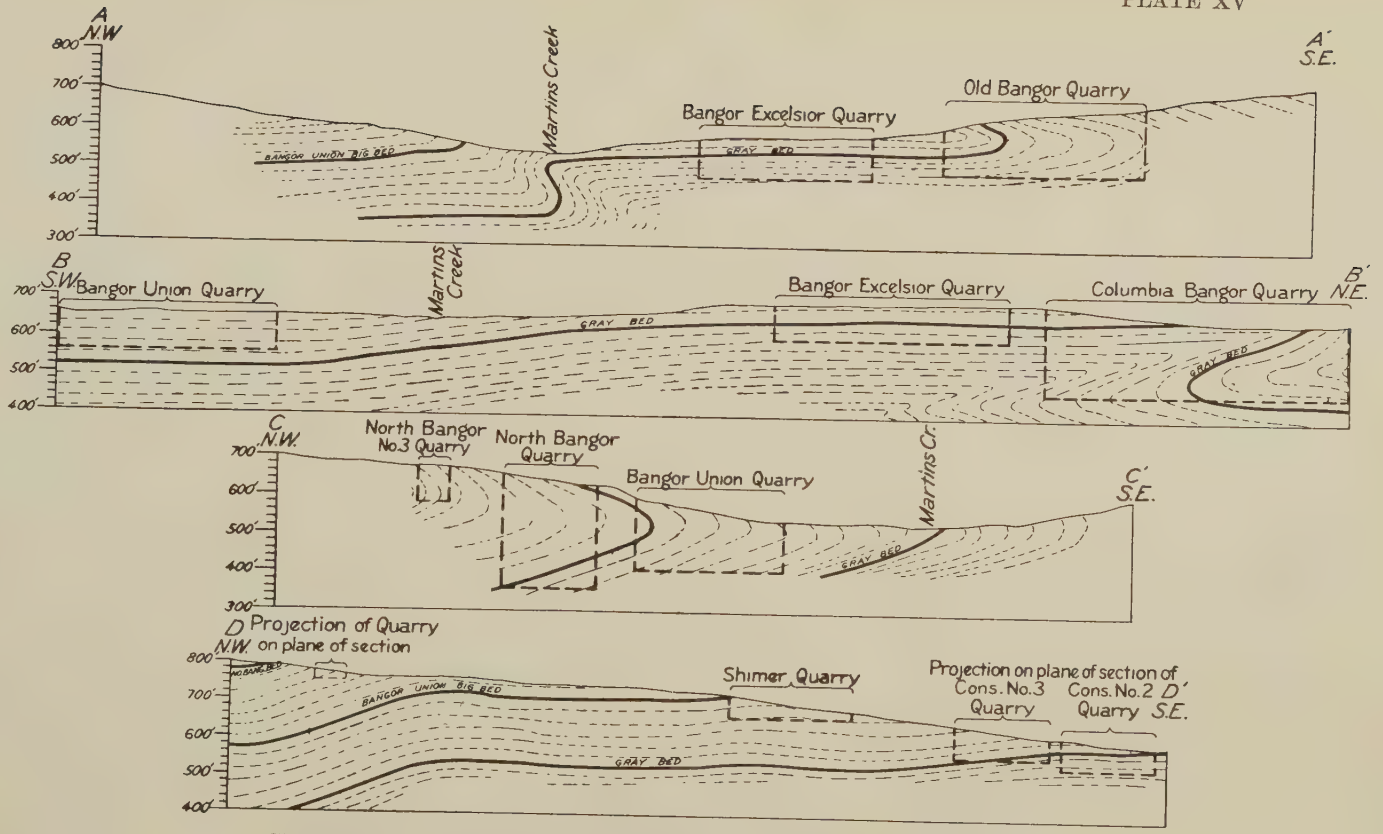
Uses.—The slate of the uppermost member of the Martinsburg formation is converted to almost all uses to which slate is adapted. The exceptionally thick beds, when quarried in large blocks, are employed for blackboards; in smaller pieces they are made into roofing slate. Beds low in carbon and hence light in color are used for electrical slate, if free from irregular siliceous or carbonaceous masses. All beds can be used for roofing slate and millstock, provided that the cleavage planes are not curved. Certain thin beds at Bangor, intermediate in color between the carbonaceous black and the typical light gray of the big beds, are used for school slate.

EFFECT OF STRUCTURAL FEATURES.

BEDDING

In places in the gently or sharply curved recumbent folds, characteristic of the district, the bedding is vertical, in others horizontal. In the hard belt profitable quarrying is not confined to one bed or group of beds; there is here no very marked difference in value between one part of the sequence and another, excepting in certain recognizable thicknesses of unusually gritty layers. In the hard belt the attitude of the beds is thus of little importance.

In the soft belt, however, structural relations of bedding are of great importance. Assume a recumbent syncline with a very small opening angle. In the limbs of such a structure the dip of the beds is very gentle, or, in the picturesque vernacular of the quarrymen, the beds "run fast." If quarrying be begun in the upper limb, as the opening is carried to a certain depth, progressively younger beds will be encountered. Beyond this the same sequence will be met, but in the reverse order.



STRUCTURE SECTIONS IN BANGOR DISTRICT; Scale 1 inch=500 feet.
AA′ Section N. 55°E. along northeast edge of old Bangor quarry.
BB′ Section N. 37°E. through Bangor Union and Columbia Bangor quarries.
CC′ Section N. 30°W. through North Bangor No. 3 quarry.
DD′ Section N. 35°W. through Shimer quarry.

If, instead, the opening angle be very large, a very much greater depth will be required to penetrate from a bed in the upper to its continuation in the lower limb of the fold. This principle is illustrated in Figure 21. It is thus seen that the larger the opening angle between the limbs of a fold, the longer a bed or series of beds remains accessible in a vertical shaft.

In the soft belt it is ordinarily desired to work or, as the quarrymen put it, to "hold" one bed, generally an exceptionally thick one, as long as possible. It is thus to the advantage of the quarrymen,

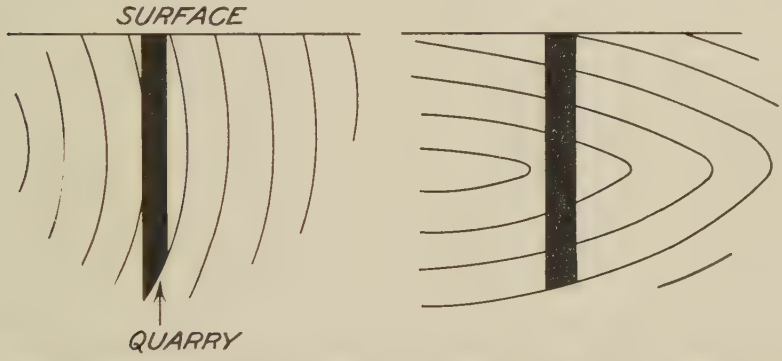


Figure 21. Advantages of open over close folding in retaining a desired bed in quarrying.

other things equal, to quarry where the folds are open and the beds nearly vertical.

CLEAVAGE

True cleavage.—The cleavage gives slate its value as a structural material. It is highly important that the cleavage yield smooth, plane surfaces. This is prevented by any one of the following three conditions:

1. Siliceous knots. These almost always make the cleavage ragged and irregular.

2. Sandy layers or "hard rolls." The cleavage generally is curved rather than plane, as it passes over sandy beds.

3. Faulting or other intense compression subsequent to the development of cleavage; in such cases the cleavage is likely to be severely curved or distorted near the fault planes.

These factors, especially the latter two, are harmful. This is not so much because they produce a condition in which the cleavage is

not perfectly plane, however. Thus, in large openings, such as the Albion quarry at Pen Argyl, the gentle curvature of the cleavage is obvious to the casual observer, in the curvature of the surfaces on which quarrying is carried on, but is not at all deleterious to successful operations because the radius of curvature is so great (Plate XI, A). But the three features named may produce sharp changes in the dip of the cleavage planes and it is these sudden variations in dip that spell doom to quarry success. Thus, a regular change in dip from 15° to 30° in 100 yards is not disastrous, but the same change in 10 feet ruins the slate so affected.

False cleavage (slip or fracture cleavage).—This feature, consisting of closely spaced small fractures, whose planes cut the true cleavage planes, affects none of the quarries in the region studied, although it is commonly observed in the middle member of the Martinsburg formation. Its development has been mentioned by Dale*, as preventing the successful quarrying of otherwise acceptable slate.

GRAIN

In the region studied, slate tends to break along surfaces which, although irregular in detail, yet coincide in general with a plane surface trending at right angles to the general strike of the cleavage. This plane of fracture is the grain, sculp, or scallop of quarrymen. The uniformity in the strike and dip of the grain is of no economic importance in itself, but associated with bedding and cleavage, it becomes a matter of great significance.

The quarries are generally opened with their sides (that is, the surfaces at right angles to the bedding strike) and their cables parallel to the grain. Further, grain and cleavage form two planes generally at angles of 90° to each other; if a third surface is broken at right angles to the two natural planes of weakness, more or less rectangular pieces can be taken out of the quarry. Grain thus facilitates the removal of the slate in regular blocks and reduces the waste developed by trimming. The relation between grain, cleavage, and bedding is illustrated in Figure 11, page 55.

MUTUAL RELATIONS OF BEDDING, CLEAVAGE, AND GRAIN

Bedding—cleavage relation.—Quarrymen speak of slate as having "length." This is the length from end to end, generally measured parallel with the grain, of a cleavage flake of slate within one bed. Thus in Figure 11, the length of slate available between the two

*Dale, T. N., Slate in the United States: U. S. Geol. Survey, Bull. 586, p.61, 1914.

black beds would be measured along the line of intersection between the cleavage and the grain plane.

A reference to Figure 22 clearly illustrates that the length thus

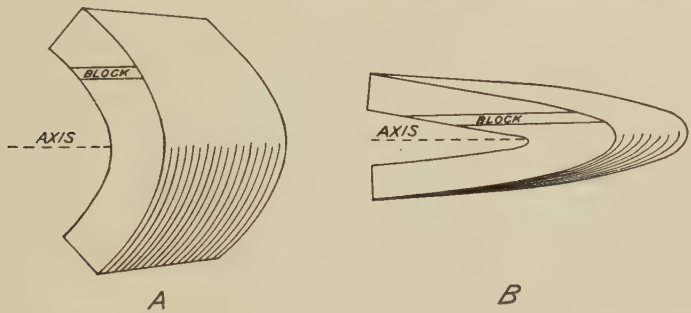


Figure 22. To show how the "length" of slate obtainable from the same bed varies inversely with the angle between cleavage and bedding.

varies approximately inversely with the angle between cleavage and bedding, and hence that, other things being equal, a quarry opened in a "tight" fold like Figure 22, B, is more profitable than one in an open fold, such as that shown in Figure 22, A. This fact presents a distinct advantage for the Bangor quarries, where the folds are generally tight. Sometimes, however, if the beds are severely thinned on the limbs by intense compression, such an advantage is nullified.

Bedding—grain relation.—As the slate is generally broken parallel to the grain, the removal of rectangular pieces, a condition favoring the reduction of trimming losses, is dependent in part on there being a right angle between grain plane and bedding strike. This is illustrated in Figure 23. In the figure on the left, rectangular blocks can be broken out between the two ribbons because the grain plane is parallel to the dip of the beds. In the figure on the right, it is impossible to break out a block of similar area with its sides parallel to the grain, without taking also some of the undesirable ribbon.

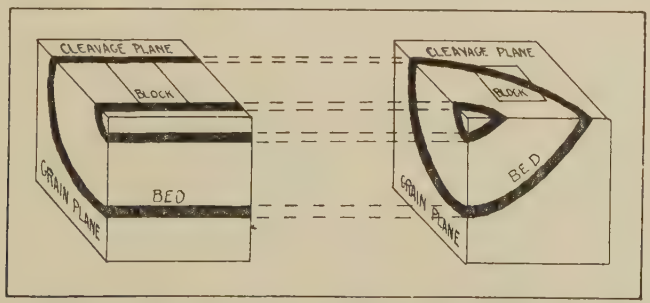


Figure 23. Diagram showing effect of relation between grain and bedding in quarrying. Relations are favorable in the figure to the left, unfavorable in that to the right.

Cleavage—grain relation.—This is not a very important factor, but quarrying is easier where the strike of the cleavage is either parallel or at right angles to the grain strike.

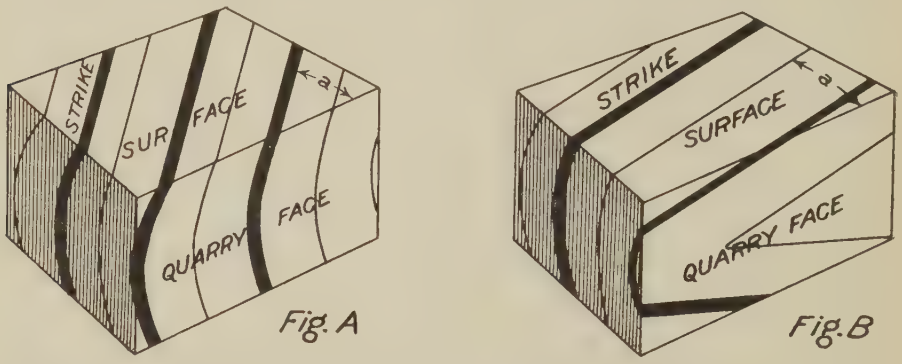


Figure 24. Diagram to show how differences in the angle between the quarry wall and bedding affect the bedding patterns on the quarry wall.

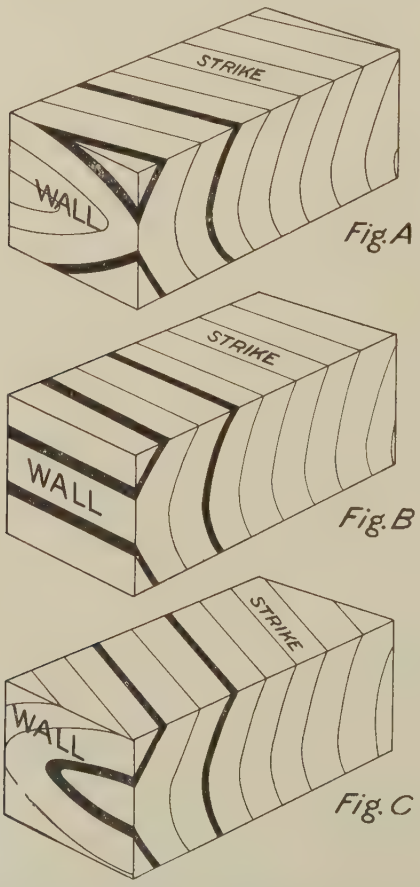


Figure 25. Diagrams to show how differences in the angle between quarry wall and bedding strike affect the bedding pattern on the quarry wall.

FAULTING

Faulting plays two roles in quarrying, according to the type of fault developed. Thrust faults of large displacement are known in the slate district, but, except for their effect in distorting the cleavage and changing the sequence of beds, such faults are negligible. Yet two other types of faults are of much importance. One of these is represented by the small movements, more or less parallel with cleavage planes, seen in the Jackson Bangor quarries. These confuse the normal sequence by causing the repetition or omission of beds. The effect of such faulting is discussed in the section on structure (p. 63).

A second type of fault is the bedding slip, in which the movement over large areas is practically parallel to the bedding. Illustrations of such displacement are furnished by the Albion Vein, Albion and New Peerless (Bangor Vein) quarries and are again discussed in the detailed descriptions of the quarries named. In these cases the movement has opened the cleavage in the adjacent slate, sometimes with the deposition of quartz in the interstices. The faulting has also developed joints which form acute angles with the plane of slippage. Near bedding-slip faults so much bad slate is thus developed that such movements become a severe bane to the quarrymen. Unfortunately they are frequently not discovered until after operations are well under way. See also page 65.

JOINTING

General plan.—Jointing has already been discussed in connection with the structures of the slate. In general, the ideal condition, from the viewpoint of the quarry operator, is met where the joint planes are approximately vertical and at right angles to the grain planes. This permits the ready removal of almost rectangular blocks from the quarry, a circumstance again favoring reduction of trimming waste.

It is a notable fact that, in the region studied, joints tend to assume a strike of about N.30-60°E., which is approximately at right angles to the prevailing direction of the grain and about parallel to the strike of the bedding. In detail, however, the generalization does not hold, and no definite law can be set down which fits all cases rigorously. Certain general facts having an economic bearing were observed, however.

Joint systems.—It was found that systems of joints present in one quarry could in many instances be recognized in another. It is probably impossible, in a region of such close folding, to trace a joint system from one quarry to another when the openings are half a mile apart. More especially is this true along the strike, for the joints are the response to stresses and these vary from place to place along the strike of the beds. However, in the few instances where one quarry has been opened approximately down the dip from another, the

correspondence between joint systems is notable. The best examples are furnished by the Albion Vein and Parsons quarries (q. v.). In these two quarries, strike and dip of bedding and cleavage are closely similar. The marked correspondence between the strikes of the two systems of joints in the two quarries is well shown by the joint diagrams.

Joints and pitching folds.—In general, as has been repeatedly pointed out, the major structural axes trend about N 60° E. Where minor folds are developed with axes transverse to the major structures there is a tendency for the joints to assume radial patterns. This is well illustrated by observations in the Consolidated No. 3 quarry, where the pitching fold, on which the Consolidated Star quarry is located, comes to the surface. Similarly, but less perfectly, jointing in the Tinsman quarry supports the same generalization. In this opening, which is on the upper limb of a syncline whose axial plane dips south, the beds in the eastern part of the quarry dip southeastward and strike about N. 70° E., while on the western wall they strike N. 80° W., dipping southward. The minor flexure thus suggested can be well seen in the bottom of the quarry. In this opening joints fall in general into two systems, striking N. 60° E., and N. 40° W., but there is little real parallelism observed. It is significant that the owners of both quarries mentioned have experienced serious difficulties in facing this problem of convergent joint planes.

Joints and faults.—As previously mentioned, where bedding-slip faults are well developed, the joints are likely to form closely spaced gashes, the planes of which make acute angles with the fault plane. The slate in such places is so badly broken into small flakes as to become virtually worthless. Some cleavage flakes are much bent and look like half-cylinders.

Where the faulting is more or less parallel to the cleavage planes, the effect on the jointing is not well marked, if noticeable at all.

DRAINAGE PROBLEMS

MEANS OF WATER INGRESS

Summary.—Water enters the quarries in five ways:*

1. Along the sides of the quarry, especially at the corners; in this case it generally represents surface run-off.
2. Along the bedding planes, particularly where there are openings between succesive beds.
3. Along open joints.
4. Along cleavage planes, notably where stringers of quartz or calcite laid down parallel to the cleavage were later in part dissolved away, so as to leave gaping openings.
5. Along shear or fault zones.

*Bowles, Oliver, Recent progress in slate technology: U. S. Bur. Mines, Reports of investigations, Serial No. 2766, p. 6, August, 1926.

The ground water surface, in such generally impervious rock as slate, is seldom horizontal. "Perched" water tables must be common and considerable hydraulic pressure is thus developed. At Slatedale, for example, the water level in two adjacent quarries, not more than 150 feet apart and both long abandoned, has been observed to differ by fifteen feet.

The "perched" water seeks any opening that will allow it to sink to ground level. Thus quarries are frequently suddenly inundated as operations expose an open cleavage crevice, joint, or partially shattered surface of shear.

Examples of water ingress.—About one mile west of Bath, on the Dannersville road, is a schoolhouse. A small opening has been made on a side road one thousand feet east of the school. In the east wall of this quarry and ten feet above its floor is a zone about two inches wide and parallel with the cleavage; this is now only partly filled with quartz, the rest of the filling having been largely dissolved away. Here and there in the crevice, traces of the cavernous quartz are still to be seen. This crevice is a good illustration of the development of open cleavage along which water enters quarries.

In the lower level of the New York quarry is a zone of movement approximately parallel to bedding and bounded by a calcareous bed showing slickensides and striae. Water enters freely along this zone and apparently connects with the ground water beyond the quarry, as the ingress of water here is said to have been synchronous with the flow from a nearby well. It appears that the shattering of the rock by the drilling of the well produced a subterranean passage-way between the general ground water and the open shear zone mentioned.

In the Tinsman quarry at Wind Gap water enters in three ways: (1) along the sides of the quarry; (2) along bedding planes, especially near the surface; (3) along joints. Some joints are partially sealed by calcite, but many are open, and even the small ones deliver much water. From one very narrow joint a gallon of water escaped in sixteen minutes.

EFFECT OF WATER ON QUARRY WALLS

Besides hindering work directly by flooding the quarry, water frequently becomes a serious danger in that it assists in developing "slides" or avalanches of rock from the quarry walls. Filling crevices and freezing, it exerts a force capable of pushing large parts of the walls into the quarry. In this way almost half of one side of a large quarry in the hard belt once fell into the opening; three men were drowned in the surge of the quarry water produced by the fall.

EXPLORATION

SURFACE EXPLORATION

Dale* has already discussed the general methods in use in exploring for slate when the rock is exposed at the surface. To this discussion nothing can be added.

CORE DRILLING

Stratigraphic interpretation.—In the region here studied, the stratigraphic location of a quarry is all-important and it is highly desirable to anticipate the beds that will be exposed in quarrying. Where the outcrop is small or where there is a heavy overburden, such that the beds cannot be determined at the surface, diamond drilling should be resorted to. Vertical drilling is then preferred, as the exact orientation of the core is made easier in the vertical position, and as the maximum thickness of beds is thus generally penetrated.

Correlation of the beds shown in the core with some portion of the slate series is next desired. If the drill has encountered the bedding at any angle other than 90°, the distance from top to bottom of a given bed, as measured in the drill core, will exceed the actual thickness of the bed. This discrepancy may be corrected, however, by the formula

$$\sin a = \frac{t}{l}$$

in which a is the angle between the bedding and the vertical direction of the drill hole, l is the distance from top to bottom of the bed measured along the core, and t is the actual thickness of the bed.

For some parts of the sequence in the uppermost member of the Martinsburg, the measurements of actual thickness have been made and are given in this report (Plates XII and XIII). From the charts mentioned, the apparent thickness can be estimated by laying a ruler across the stratigraphic column in such a way as to form an angle with the horizontal lines of the column equal to the acute angle between the vertical bore hole and the bedding. As the scale employed in these thickness charts is known to be one inch on the chart for 200 inches of actual thickness of slate, the apparent thickness (that is, the actual length from top to bottom of the given bed, as measured parallel to the length of the drill core) can be quickly estimated. This procedure is shown in Figure 26.

*Dale, T. N., The slate belt of eastern New York and western Vermont: U. S. Geol. Survey, Nineteenth Ann. Rept., part III, pp. 271-272, 1899.

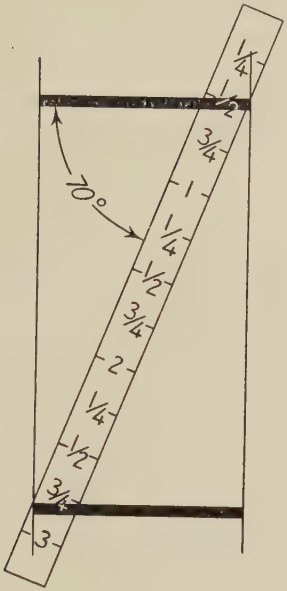


Figure 26. Method of using thickness charts in estimating apparent thickness of beds.

Depth of drilling.—If the problem, instead of being one of determining what beds are being drilled through, becomes that of estimating the depth required in drilling or quarrying to a given desired bed, correlation with some known slate horizon must first be established. When a known bed *b*, is recognized, at the surface, the actual thickness of slate separating *b* from the required bed *c* is obtained by reference to the thickness charts or to any other data that furnish

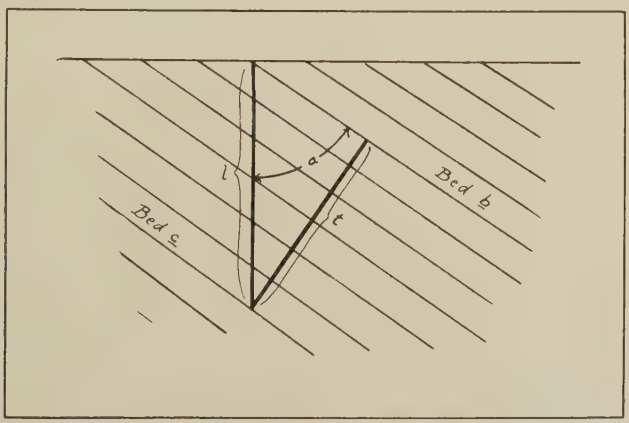


Figure 27. Method of estimating depth of any desired bed *c*, when bed *b* is recognized at the surface and actual thickness *t* is shown by the thickness chart.

this information. The formula previously given is then applied again, but in this case t is known and l is the required value; hence

$$l = \frac{t}{\sin a}$$

where t is the actual thickness of slate intervening between the beds b and c, the angle a is the acute angle between the bedding and the drill hole, and l is the depth to which drilling or quarrying must be carried to strike the bed c. These relations are shown in Figure 27.

If an overburden is passed through before drilling into the bed b the thickness of the overburden should be omitted in applying the formula given above, but should be added after the value of l has been obtained, in order to give the total distance below the surface which must be traversed to strike the bed c.

Orienting drill cores.—As the drill core is removed from the hole, it is frequently rotated somewhat around its long axis. Again, the driller may mark carefully the direction of its orientation after withdrawal of the core from the hole. In either case the direction of dip of the beds remains uncertain. In such instances, the following principles may serve as guide in the district here described:

1. The cleavage is generally horizontal or dips southward. Hence, when the core is vertical, if the beds dip more steeply than the cleavage, the dip of the beds is south.
2. The grain always trends N. 30-65° W. If a bit of the core is chipped to determine the direction of the grain or sculp, the exact orientation of the core can be assured, as is shown in Figure 28.

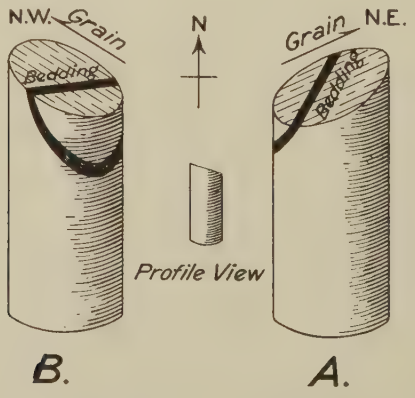


Figure 28. To show how grain can be used to orient cylindrical drill cores; A, incorrect orientation; B, correct orientation; cleavage dips south in A, but grain trends northeast; cleavage dips south and grain trends northwest in B.

The importance of drilling.—Too much can scarcely be said in favor of exploring with a diamond drill before buying slate land or opening a quarry. Though the slate may appear good at the surface, no method of prognostication has yet been devised, even by the most experienced practical quarrymen, by which the continuance in depth of favorable composition and structure can be assured.

Every innovation which reduces the element of chance in slate quarrying is to be welcomed. Proper core drilling, planned and conducted by an experienced operator, is a further safeguard against that waste of money and effort which has made the mining and quarrying industry anathema to many, and of really large profit to but few.

THE VALUATION OF SLATE LANDS*

METHODS OF VALUATION

As a basis for determining the present value of slate land, it is necessary to find the value of similar land adjoining that in question. From this base value, the appraiser may determine the reflected value of the land to be appraised.

This value of adjoining similar land is referred to as the normal market value, that is, the value it possesses in an open market between a willing seller and a willing buyer. There are various methods of determining this market value, dependent upon the circumstances in individual cases. Three chief sources of information are available to the appraiser; namely, sales, opinions, and assessments.

It has been found by the Bureau of Valuation, during nearly ten years of the prosecution of its work, that the first source, sales, is by far the most reliable indication of true market value. Sales are tangible; in the majority of cases, all the facts pertaining to a sale can be ascertained; parties thereto can be interviewed; and facts stated with certainty. Not all sales, however, are usable or applicable. Some are found to be impossible of correct analysis; some are found not to be bona-fide transfers; some are too old; some are too remote from the vicinity of the land to be appraised; some involve land entirely dissimilar to that examined. But the weight of the authority of court decisions is that in valuation cases actual bona-fide sales of property are the most reliable indication of market value.

Opinions, in the absence of sales or other information, offer a guide to the appraiser in arriving at a conclusion of value. But there are many pitfalls in making of opinions. Not all men are qualified to speak with authority on the subject of land values. The men selected should be thoroughly familiar with values in a given territory, and

*This summary of land valuation principles, as applied to slate lands, is taken from a slightly altered personal communication prepared by Mr. Homer H. Kirby of the Bureau of Valuation, Interstate Commerce Commission, who has been engaged in the valuation of slate lands in Northampton County.

they should be capable of rendering an impartial expression of opinion.

Assessments, generally, cannot be relied upon without some other check. Assessed values are rarely, if ever, true values, although the law in many instances requires that property be assessed at true values. Usually, the requirement is that the assessed value be a specified percentage of the true value. But most assessors will acknowledge that they do not place a true one hundred per cent valuation on property for purposes of taxation, even where such is the requirement under the law. And where the assessor attempts to make his valuations on the basis of a certain percentage of the true value, it is almost invariably found that there is no real uniformity in the application of his ratio.

It is generally desirable to establish the value of land upon the basis of naked land value plus minerals. To do this, the presence of slate must be determined. The answer to the question as to the existence or non-existence of slate is not difficult to find. Geological survey maps show graphically the location of slate deposits in relation to the land appraised.

The answer to a second question, namely, what market value do such slate deposits, in the ground, possess, is not so easily found. A local investigation of this question is best made by ascertaining what sales, if any, of slate lands have occurred recently or during the last five or ten years, and by interviewing men engaged in the industry, for the purpose of securing authoritative information as to what value should be attached to such lands.

Most of the transfers of slate-bearing lands involve heavy improvements and developments. In the majority of instances, sale of the land carries with it buildings, machinery and cost of stripping and developing an existing "hole." The value of these developments and improvements must be known, or ascertained. At best, the results obtained by making deductions based on such estimates are pretty much of a guess.

At the beginning of the industry in this region, there was considerable prospecting and "wildcatting." In the enthusiasm of pioneer development, fabulous prices were paid for presumably slate-bearing lands. When the fever was on, every man's farm situated in the slate region was looked upon as a potential fortune because of the slate presumed to be contained in the ground. Many of these early ventures turned out to be failures.

It is always pretty much of a gamble as to what will be the result after a costly quarry development has been made. It may transpire that the slate will be found to be useless for profitable commercial purposes. Its quality may be inferior to the average. The strata

may take unexpected twists and bends, thus rendering the slate unfit for the high-standard use to which it is generally put. But this is a matter that cannot be definitely known until after considerable development is carried out.

CONCLUSIONS

Because of the uncertainty surrounding any quarry development, it is the consensus of opinion of most of the men interviewed, who are connected with the industry, that slate lands are not worth anything, in excess of bare land or surface value, until proven. At the present time, no operator or company will buy lands for quarry purposes, until it has been proven that slate in commercially profitable quantities can be gotten out,—that is, until some preliminary development has been done. And, even then, it is a "gamble." One quarry may be profitably operated, and another immediately adjoining may prove to be a failure.

From a careful consideration of all the facts, therefore, and bearing in mind the influence exercised by them on the market value of slate in the ground, in an undeveloped state, the writer has reached the conclusion that the slate-bearing lands examined in Northampton County, Pennsylvania, do not in general possess any special market value by reason of such slate deposits, before the slate has been quarried. Until then the only value is that inherent in the surface of the land for farm or other purposes. Any other element of value is too intangible to determine. The value may be enhanced by individual preference or special factors, but no general standards can be laid down to govern such exceptional cases.

QUARRY DESCRIPTIONS.

INTRODUCTORY STATEMENT

As has been previously stated, the slate quarries in the district under consideration fall into two groups,—those of the soft belt and those of the hard belt. The former are more numerous and economically the more important today, yielding a greater variety of slate products. They group themselves generally around recognizable centers, of which Bangor, Pen Argyl, and Wind Gap are most important. The hard belt quarries are less localized. The most important centers of production now are Edelmans, Belfast, and Chapman. Twenty-six companies were quarrying in the soft belt during 1923, and twenty-nine separate holes were furnishing their material; in the hard belt five quarry holes were being worked by four companies.*

For the purpose of ease in finding, the quarries, as indicated on the quarry maps, have been separated into groups. These groups generally are fairly closely knit economic units, shipping slate from the center or centers after which each has been named. The quarries and

* In 1926, only two companies were operating hard slate quarries.

companies are listed below in the appropriate group. Wherever possible, the name by which the quarry is known in the immediate neighborhood is given, to facilitate its finding in case the reader desires to learn more about it. In a few instances alternative names are added in parentheses, where more than one name is applied. In the case of many of the older and abandoned quarries no name could be found. Similarly, the name of the company or individual operating or owning the property is given, where possible, together with the address, again to facilitate inquiry. The list is arranged so as to progress from the east westward across the soft belt and similarly across the hard belt. Quarries operated in 1923 are marked with an asterisk. The numbers correspond to those used on the geologic map (Plate II).

Soft Slate Quarries (Soft Belt)

SLATEFORD GROUP:

1. Name unknown.
2. Washington Brown quarry.
3. Williams quarry; Frank Williams, Slateford, Pa.
4. Snowdon quarry.
5. Frye quarry; Scranton Iron Co., Scranton, Pa. (?)

BANGOR GROUP:

*1. New York quarry; Woodley Slate Co., Bangor, Pa.
2 Hoboken quarry; J. F. Houck, Stroudsburg, Pa.
3. Strunk quarry.
*4. New Peerless (Bangor Vein) quarry; Bangor Vein Slate Co., Bangor, Pa.
5. Little Bangor quarry.
6. Name unknown.
7. Mountain View quarry.
*8. Consolidated No. 3 quarry; East Bangor Consolidated Slate Co., East Bangor, Pa.
9. Shimer quarry; Shimer Slate Co., Bangor, Pa.
10. Consolidated No. 2 quarry; East Bangor Consolidated Slate Co., East Bangor, Pa.
*11. Consolidated No. 1—Star quarry; East Bangor Consolidated Slate Co., East Bangor, Pa.
12. Standard quarry.
13. Bangor Valley (Bangor Eclipse) quarry; D. Howell Estate, Easton, Pa.
*14. Bangor Central quarry; Bangor Central Slate Co., Easton, Pa.
15. Bangor Royal quarry.
*16. Columbia Bangor—New Bangor quarry; east end owned by Columbia-Bangor Slate Co.; west end owned by Bangor Ideal Slate Co., East Bangor, Pa.
17. Bangor Excelsior quarry; Bangor Ideal Slate Co., East Bangor, Pa.
*18. Old Bangor quarry; Amalgamated Slate Quarries Co., Drake Bldg., Easton, Pa.
*19. North Bangor No. 3 quarry; North Bangor Slate Co., Bangor, Pa.
*20. North Bangor No. 1 quarry; North Bangor Slate Co., Bangor, Pa.
*21. Bangor-Union quarry; Auld and Conger Co., Cleveland, Ohio.
*22 Bangor Washington quarry; Bangor Washington Slate Co., Bangor, Pa.
*23. Northampton quarry; North Bangor Slate Co., Bangor, Pa.
24. Shaft on property of W. L. Blake, Bangor, Pa.

WIND GAP—PEN ARGYL GROUP:

1. Nungesser quarry.
*2. Albion-Bangor (Blue Mountain) quarry; Albion Bangor Slate Co., Wind Gap, Pa.
*3. Arvon quarry; Arvon Slate Co., Wind Gap, Pa.
4. Excelsior quarry; John F. Hess, 425 Paxinosa Ave., Easton, Pa.
5. Pelican quarry; Plainfield Slate Co. (?)
*6. Tinsman quarry; The M. L. Tinsman Co., Wind Gap, Pa.; J. W. Williams, Easton, Pa.
7. Allen quarry; W T. Allen Estate, Wind Gap, Pa.

8. Kinney quarry; Wm. Evans, Wind Gap, Pa.
*9. Phoenix quarry; Phoenix Slate Co., Wind Gap, Pa.
10. Heller quarry; Dr. J. C. Heller, Wind Gap, Pa.
11. Imperial quarry; Imperial Slate Blackboard Co., Wind Gap, Pa.
12. Acme quarry; Colonial Slate Co., Bangor, Pa.
*13. Alpha quarry; Colonial Slate Co., Bangor, Pa.
14. Name unknown.
15. Name unknown.
16. Albion Superior quarry; Amalgamated Slate Co., Easton, Pa.
17. Stoddard quarry; D. Stoddard & Son, Bangor, Pa.
18. Dick quarry.
19 Martin & Harding quarry.
20. Doney's Old quarry.
21. Grand Central quarry; Thos. D. Moulds, Philadelphia, Pa.
22. Small Grand Central quarry; Thos. D. Moulds, Philadelphia, Pa.
23. Name unknown.
*24. Doney quarry; Doney Slate Co., Pen Argyl, Pa.
*25. New Diamond quarry; Diamond Slate Co., Pen Argyl, Pa.
*26. Parsons quarry; Parsons Bros. Slate Co., Pen Argyl, Pa.
*27. Albion Vein quarry; D. Stoddard & Son, Bangor, Pa.
28. Name unknown.
*29. Albion quarry; east end owned by Stephens-Jackson Co., Pen Argyl, Pa.; west end owned by Keenan Structural Slate Co., (Albion Slate Co.), First Natl. Bank Bldg., Bangor, Pa.
*30. Jackson Bangor No. 7 quarry; Jackson Bangor Slate Co., Pen Argyl, Pa.
31. United States quarry; Jackson Bangor Slate Co., Pen Argyl, Pa.
*32. Hercules (Masters or Bolger) quarry; Belmont Slate Co., Bangor, Pa.
33. Pennsylvania quarry; Jackson Bangor Slate Co., Pen Argyl, Pa.
34. Diamond quarry; Jackson Bangor Slate Co., Pen Argyl, Pa.
*35. Jackson Bangor No. 6 quarry; Jackson Bangor Slate Co., Pen Argyl, Pa.
36. Jackson Bangor No. 6 quarry (small hole); Jackson Bangor Slate Co., Pen Argyl, Pa.
*37. Jackson Bangor No. 5 (Valley) quarry; Jackson Bangor Slate Co., Pen Argyl, Pa.
38. Name unknown.
39. Name unknown.
40 Old Crown quarry; Crown Slate Co., Pen Argyl, Pa.
41. Crown quarry; Crown Slate Co., Pen Argyl, Pa.
42. Bangor Fidelity quarry; Bangor Fidelity Slate Co., Pen Argyl, Pa.
*43. West Bangor quarry; Bangor Fidelity Slate Co., Pen Argyl, Pa.
44. Bangor Superior small quarry; Slate Products Co., Bangor Pa.
*45. Bangor Superior quarry; Slate Products Co., Bangor, Pa.
46. Keller quarry.
47. Stecker quarry.
48. Uhler quarry; Mr. Uhler, Bangor, Pa.
49. Uhler quarry; Mr. Uhler, Bangor, Pa.
50. American Bangor quarry; American Slate Co., Drake Bldg., Easton, Pa.
51. Bangor Southern quarry; American Slate Co., Drake Bldg., Easton, Pa.
52. Reichard quarry; Dr. Reichard, Bangor, Pa.
53. Reichard quarry; Dr. Reichard Bangor, Pa.
54. Delabole quarry; American Slate Co., Drake Bldg., Easton, Pa.
55. Name unknown.
56. Name unknown.
57. Nagel quarry.

POINT PHILLIP GROUP:

1. West End quarry.
2. West End quarry.
3. Beers quarry; Geo. Beers, Newton, Pa.
4. St. Nicholas quarry; Geo. Beers, Newton, Pa.
5. Young quarry; Chas. Stahley, Point Phillip, Pa.

SLATEFIELD GROUP:

1. Seip quarry; Henry Seip, Danielsville, Pa.
2. Labar quarry; Oliver Labar, 1st National Bank Bldg., Bangor, Pa.
3. Name unknown.
4. Name unknown.
5. Langenbach No. 1 quarry.
6. Langenbach No. 2 quarry.
7. Langenbach No. 3 quarry.
8. Williams No. 1 quarry; Tom Wiliams Slatington, Pa.
9. Williams No. 2 quarry; Tom Williams, Slatington, Pa.
10. Williams Shaft; Tom Williams, Slatington, Pa.

Hard Slate Quarries (Hard Belt)

PORTLAND GROUP:

1. Northampton quarry.
2. Mt. Bethel quarry; Willard Hartzell, Mt. Bethel, Pa.
3. Phillips quarry; H. and W. Phillips, R. D. 1, Portland, Pa.
4. Miller quarry; Mrs. Stella Miller, R. D., Portland, Pa.

UNCLASSIFIED:

Quarry 1-2 mile west of Johnsonville; not strictly a hard belt quarry.

FLICKSVILLE GROUP:

1. Pysher quarry; Paul T. Pysher, R. D. Flicksvillle, Pa.
2. Doster quarry; H. A. Doster Estate, Bethlehem, Pa.
3. Wagner quarry; Josiah Ruch, Flicksville, Pa.
4. True Blue quarry.
5. Friedman quarry; Friedman Bros., Scranton, Pa. (?)
6 Delabole quarry.

BELFAST—EDELMAN GROUP:

1. Batt quarry.
2. Garr quarry.
3. Lehr quarry.
*4. Edelman quarry; Theo. Whitesell and Co., Easton Natl. Bank Bldg., Easton, Pa.
5. Barnett quarry.
6. Pennsylvania quarry; Pennsylvania Hard Vein Slate Co., Geo. W. Geiser, Northampton Natl. Bank Bldg., Easton, Pa.
7. Seem quarry; Jacob H. Seem, Bath, Pa.
8. Allen quarry.
9. Northampton quarry (two openings); Northampton Hard Vein Slate Co., Easton National Bank Bldg., Easton, Pa.
10. Property of Northampton Hard Vein Slate Co., Easton Natl. Bank Bldg., Easton Pa.
11. Property of Theo. Whitesell Co., Easton National Bank Bldg., Easton, Pa.
12. Theo. Whitesell quarry; Theo. Whitesell Co., Easton National Bank Bldg., Easton, Pa.
13. Property of Theo. Whitesell Co., Easton National Bank Bldg., Easton, Pa.
14. Property of Theo. Whitesell Co., Easton National Bank Bldg., Easton, Pa.
15. Pritchard quarry; Clyde Pritchard, R. F. D. 2, Easton, Pa.
16. Old Belfast quarry; Belfast Slate Co., Nazareth, Pa.
*17. Belfast quarry; Belfast Slate Co., Nazareth, Pa.
18. Name unknown.
19. Henry quarry; G. W. Metz, R. D., Nazareth, Pa.
20. Name unknown.

CHAPMAN GROUP:

1. Graber quarry.
2. The Welshman's quarry.
3. Ryan quarry; E. P. Wilbur Trust Co., Bethlehem, Pa.
4. Bethlehem quarry; E. P. Wilbur Trust Co., Bethlehem, Pa.
*5. Chapman Standard quarry; Chapman Slate Co., Myers Bldg., Bethlehem, Pa.
*6. Chapman quarry (two openings); Chapman Slate Co., Myers Bldg., Bethlehem, Pa.
7. Keystone quarry; Keystone Slate Co., 511 Bullitt Bldg., Philadelphia, Pa.
8. Name unknown.
9. Wagner quarry.
10. Fisher No. 2 quarry.
11. Fisher No. 1 quarry.
12. Lilly No. 1 quarry.
13. Lilly No. 2 quarry.
14. Fisher No. 3 quarry.
15. Name unknown.
16. Mauch Chunk quarry.
17. Chapman Superior quarry.
18. Ed Smith quarry.
19. Hagenbusch quarry; Clinton Hagenbusch, Nazareth, Pa.
20. Turner quarry.
21. Reading quarry.
22 Magee quarry; Clarence Wolle, Bethlehem, Pa.

23. Rippon & Wolle quarry; Clarence Wolle, Bethlehem, Pa.
24. Schlegel quarry; Wm. Schlegel, R. F. D. 2, Bath, Pa.
25. Steckel No. 1 quarry.
26. Steckel No. 2 quarry.
27. Dick quarry.
28. Name unknown.
29. Rhymer quarry.
30. Name unknown.
31. Roth quarry.
32. Achenbach quarry; Dexter Cement Co., Nazareth, Pa. (?)
33. Fleischman quarry; Dexter Cement Co., Nazareth, Pa. (?)
34. Daniels quarry; Dexter Cement Co., Nazareth, Pa.
35. Bader quarry; Joe Bader, R. D., Nazareth, Pa.
36. Roon quarry; Edward Roon, R. D. 1, Nazareth, Pa.
37. Hayer quarry; Israel Hayer, Hecktown, Pa.
38. Name unknown.

SEEMSVILLE GROUP:

1. Koch quarry.
2. Name unknown.
3. Ziegenfuss quarry; Mrs. Ziegenfuss, R. D., Bath, Pa.
4. Name unknown.
5. Name unknown.
6. Miller quarry.
7. Miller quarry No. 2.

Operating quarries either sell their slate directly or distribute it through a selling firm. A list of the types of slate products yielded is given under the description of each quarry.

In addition to those quarries and companies which now produce or have in the past produced some variety of slate products, there were also obtained the following names of companies in this district which act as distributors, selling but not quarrying; these concerns may cooperate more or less intimately with special quarrying companies.

Bangor Structural Slate Co., Bangor, Pa. Sellers of blackboard slate, electrical slate, roofing slate, and slate for structural and sanitary purposes.

Butler Bros. Co., Pen Argyl, Pa. Makers of marbleized slate.

Griffin Bros., Bangor, Pa. Makers of school slate.

Natural Slate Blackboard Co., Pen Argyl, Pa. Sellers of slate blackboards.

Structural Slate Company, Pen Argyl, Pa. Sellers of electrical slate and of slate for structural and sanitary purposes.

Vendor Slate Co., Drake Bldg., Easton, Pa. Sellers of roofing slate.

In the following descriptions of quarries, the numerals appearing with the quarry names are the same as those given in the quarry list above and on the geologic map, Plate II. The quarries are discussed in the order in which they are listed above.

SOFT SLATE QUARRIES

Slateford Group

SUMMARY

The quarries of this group are all within a mile of Slateford and would, when operating, obtain their supplies and ship their products from Slateford. They are opening wholly in the soft belt, that is, the slate is soft to the chisel, has well developed cleavage, and is distinguished by the greater distance which separates the "ribbons," or, to put in another way, by the width of the individual beds.

The sequence of the subdivisions of the Martinsburg, as already explained, is, in the order of superposition, the oldest beds below:

Pen Argyl beds
Bangor beds
Middle, sandy member
Lower, hard slate member

Within the Bangor and Pen Argyl beds themselves, the quarrymen have designated several individually recognizable and generally exceptionally thick strata. These have already been described in this report under the section dealing with the economic geology of the slate. The reader should refer to that section for the sequence of the various big beds and "runs" (pages 105, 106).

The northern edge of the middle, sandstone member of the Martinsburg formation appears in the bottom of Slateford Creek, east of Williams quarry and on the hillside to the south, a few hundred feet east of the Frye quarry. It is clear, therefore, that the Frye quarry is in the Grand Central "run", and it is highly probable that the Williams and Snowdon quarries are higher in the Bangor beds. Quarry Number 1 in this group and the Washington Brown quarry are more probably in the Pen Argyl beds, since it would seem that a considerable thickness of slate lies between these and the holes first mentioned; further, where the old road from the Snowdon quarry crosses the west branch of Slateford Creek three-tenths of a mile west of Williams quarry, heavy sandy beds show in the creek bottom, strongly suggesting the sandy layers at the top of the Bangor beds.

In the quarries of this group, the dip of the beds is generally gentle; the cleavage has a fairly uniform strike, which is generally northeast, but in places in the northern openings the cleavage planes dip north. The grain is uniformly northwesterly in trend. Jointing was not studied with care here. Faulting is conspicuous, having been described in both the Snowdon and Williams quarries.

The products included roofing slate, blackboards, electrical slate, and sanitary and structural materials. All of the quarries here are abandoned.

The numbers given with the quarry names below correspond to those on the quarry location map; reference to this map will locate the quarry in question.

1. QUARRY

Location and dimensions.—This is a small rectangular opening measuring about 40 feet in a northeast direction by 80 feet in a northwest direction; it shows 20 feet of slate above the water level. The hole lies west of and about 100 feet above the Delaware Water Gap highway, immediately behind a house. Only a small dump is visible.

Geology.—The beds strike N. 45° E. and dip from 22° to 37° N., flattening northward. The cleavage strikes N. 45° E. and dips 10-25° N., also flattening northward. The beds are from three to six inches thick; a few are two inches thick and so sandy as to show no slaty cleavage. A few fractures were observed dipping two or three degrees more steeply than the cleavage and in the same direction.

History and development.—The quarry has long been abandoned and is now full of water. Nothing is known of its history, but it appears not to have been worked for at least thirty years.

2. WASHINGTON BROWN QUARRY

Location and dimensions.—This is an old quarry near an isolated farm house which overlooks Delaware River and is situated on the plain at the foot of the talus slope of Blue Mountain. It measures 125 feet in a northwesterly direction by 50 feet toward the northeast and is roughly rectangular. Its walls rise only about three feet above the water with which the hole is now filled. Its depth must be at least 100 feet, judging by the size of the dump.

Geology.—The beds strike N. 42° E., dipping 21° NW. The slate appears to be of fair quality, not heavily ribboned, but there are some sandy beds. The material on the dump shows considerable rusting, but an absence of heavy jointing and little indication of quartz or calcite stringers. The cleavage strikes N. 25° W. and dips 18° SW.

History.—This is probably the quarry described by R. H. Sanders[99] and examined by him at some time between 1874 and 1878. That investigator said that the quarry had just been opened at the time of his visit.

3. WILLIAMS QUARRY

Location and dimensions.—This quarry is in the valley of Slateford Creek about half a mile from its mouth. It is an amphitheater, whose sides are formed by the valley walls. Sixty feet of slate are exposed on the creek's southwest wall. The opening measures 180 by 150 feet.

Geology.—At the south end of the cut the bedding strikes N. 50° E., dips 20° NW.; in the north end it strikes N. 50° W. and dips 20° SW. The cleavage has a strike of N. 60° E., and dips 20-25° S. It appears, therefore, that both ends of the cut are on the under limb of a fold the axial plane of which dips gently southward; at the southern end of the opening the dip is north, as this hypothesis would require, while at the northern end, preparing for a rise over the axial plane of the complementary fold below, a southward dip appears.

[99] Sanders, R. H.: Geology of Lehigh and Northampton Counties: Second Geol. Survey, Pennsylvania, D[3], vol. I, p. 86, 1883.

A set of small, rather inconspicuous, calcite-filled joints strikes N. 70° E. and dips 36° SE., just under a calcite-filled fault, which appears on the south wall of the quarry near the creek level, striking N. 20° E. and dipping 16° NW. A small calcareous seam parallel to the bedding shows the same minute crumpling and faulting already described as common in these calcareous stringers (p. 68).

History and development.—This quarry was described by Rogers[100] as being operated in 1858 by the Pennsylvania Slate Company. It was first opened in 1832 by Sam Taylor, then came into the hands of John Williams in 1850, and is at present on the property of Frank Williams of Slateford. It is not now being worked.

4. SNOWDON QUARRY

Location and dimensions.—This quarry is immediately west of an old road that runs parallel with Slateford Creek, six-tenths of a mile west and slightly south of the town of Slateford. It is 350 feet long in a northeasterly direction and 200 feet wide and is virtually rectangular. It is now filled with water to within 30 feet of the top. A large dump is present.

Geology.—At the southeastern edge, the beds appear to dip gently toward the south, probably not over 15°; at the northwestern side they seem to steepen so as to dip as much as 60°, but as the sides were not accessible and the bedding indistinct these observations are poor. They fit, however, with the conception developed for Williams quarry (see above), for the beds here would then be the upper limb of a fold complementary to and above that whose lower limb is seen in Williams quarry. The strike of the bedding is parallel to that of the cleavage. The cleavage is very uniformly N. 45° E. and dips 28° SW. The slate, though rather heavily ribboned, is soft and apparently easily

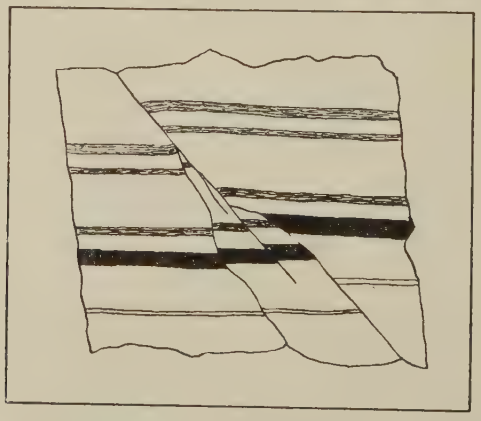


Figure 29. Sketch of small fault; entire fault trace is 16 inches long. From dump of Snowdon quarry.

[100] Rogers, H. D.: Geology of Pennsylvania; vol. I, p. 248, 1858.

sawed. It bears some calcite and quartz on its joint faces and a little pyrite occurs with the calcite.

In his description of this quarry, Sanders[101] mentions a fault, but this could not be seen. However, small-scale faulting was observed in some of the blocks on the dump. (See Figure 29.)

History and development.—This quarry is said to have been opened in 1870. It was then owned by H. P. Jones. Later it was purchased by R. S. Brown. It is now a portion of the R. S. Brown estate. Operations were discontinued about ten years ago.

The quarry property still bears a mill, with remnants of a large engine, four vertical slate saws, a buffer, and other equipment. Two cables, one fitted with a pulley frame, are yet in evidence.

5. FRYE QUARRY

Location and dimensions.—This quarry lies southeast of a road that leads southwestward from Slateford. It is about three tenths of a mile from the town. The opening is an elongated cut trending 210 feet in a northeasterly direction, with a maximum width of 85 feet. Its greatest depth below the surface is twenty feet. There is no water in the bottom. A rather small dump lies adjacent to the quarry and some waste slate is to be seen across the road.

Geology.—The beds are generally indistinct, but, taking the quarry as a whole, appear to strike N. 32° E., virtually horizontal, the beds dipping 2° W. in one place and 3° E. in another. The cleavage has a strike like that of the beds, but dips 35° SE., which fits in with the conception that the beds here are slightly lower than those exposed in the Snowdon and Williams quarries but are in about the same position structurally as the Snowdon quarry beds, i. e., on the upper limb of an anticline so far overturned to the north as to give it a nearly flat axial plane dipping gently south (see structure sections).

The slate is cut by occasional joints roughly parallel to the strike of the cleavage, and dipping steeply southeast; these are calcite filled.

The slate is of poor quality. There are some beds 1½ feet thick, but these are rare and the material is faintly sandy. There is considerable rusting.

No overburden is visible except 1½ feet of weathered slate.

History and development.—This quarry was worked before about 1875 and Sanders[102] found it abandoned. Mr. Frank Williams of Slateford states that it was owned and operated at one time by the Scranton Iron Company, but never yielded much slate. No machinery remains.

[101] Sanders, R. H.: Op. cit., p. 89.
[102] Sanders, R. H.: Op. cit., p. 89.

Bangor Group

SUMMARY

The Bangor group quarries are mostly close to the town of Bangor All of them secure the major part of their supplies from Bangor; it is their shipping point, and the men employed are mainly residents of Bangor and East Bangor. True, the New York quarry, which is the farthest out, lies about three miles by road from the city. Yet the greater part of the openings included in this group are not more than half a mile from Bangor or East Bangor post offices and lie on either side of the State highway connecting these two towns.

The quarries of the Bangor group are, like those at Slateford, in the soft belt. The sequence of the minor divisions of the Martinsburg formation has been described in treating of the Slateford quarries and on pages 105, 106. The big beds mentioned in that description may be identified in the quarries of the Bangor group and were first named in them. At Johnsonville, 4½ miles northeast of Bangor (see Plate II), there is a narrow strip of the hard slate, followed to the north by a section almost a mile wide underlain by the middle, sandy member of the Martinsburg formation. North of the sandy member is soft slate, succeeded by a belt of rock more sandy than the normal soft slates. This sandy belt marks the northern limit of the Bangor beds. It is traced westward toward Bangor with difficulty, so that the northern edge of the Bangor beds is not generally identifiable in the field and a doubt consequently exists as to the location of the line between the Bangor and Pen Argyl beds. South of and stratigraphically lower than the sandy slate near the top of the Bangor beds, however, are almost all the quarries of the Bangor group. The exceptions are the New York, Hoboken, and Northampton quarries, which appear to be too far north of the lower part of the Bangor beds to be included in that member of the Martinsburg formation. Although absolute correlation is lacking for these three quarries, it appears probable that they occupy a stratigraphic position somewhere immediately above or below the Albion "run" in the Pen Argyl beds.

The quarries of the Bangor group lie on folds of which the limbs are generally closely apposed and the axial planes almost horizontal. Consequently it is not rarely the case that an opening, beginning at the surface in beds dipping southward at low angles will, as greater depth is acquired, traverse the same beds but in the inverse order and dipping north. The change in the angle of dip will thus rapidly alter the width of outcrop of the beds. To this may be added, as another factor in the production of irregularity in width of outcrop, the topographic effect; for the relief, or difference in altitude between the hills and valleys, is far greater at Bangor than elsewhere in the

soft belt and its effect in shifting the outcrop of the Bangor beds, dipping at gentle angles, is marked. These features combine to necessitate the greatest caution in foretelling what beds will be met with in a new quarry opened in the Bangor region.

The Bangor group of quarries exposes several folds. One of these is the Old Bangor syncline. Both limbs of this structure appear in the Old Bangor, Bangor Union, North Bangor, and North Bangor No. 3 quarries. The lower limb alone appears in the other quarries at Bangor and East Bangor. The Columbia Bangor quarry shows, in addition a small syncline immediately below this lower limb, developed apparently as a drag fold, so that the lower limb of the Old Bangor syncline, as seen in the New Bangor quarry is virtually continuous with that in the Bangor Central opening.

Another small syncline, but in this case with the limbs especially closely apposed, is to be seen in the New Peerless (Bangor Vein) quarry.

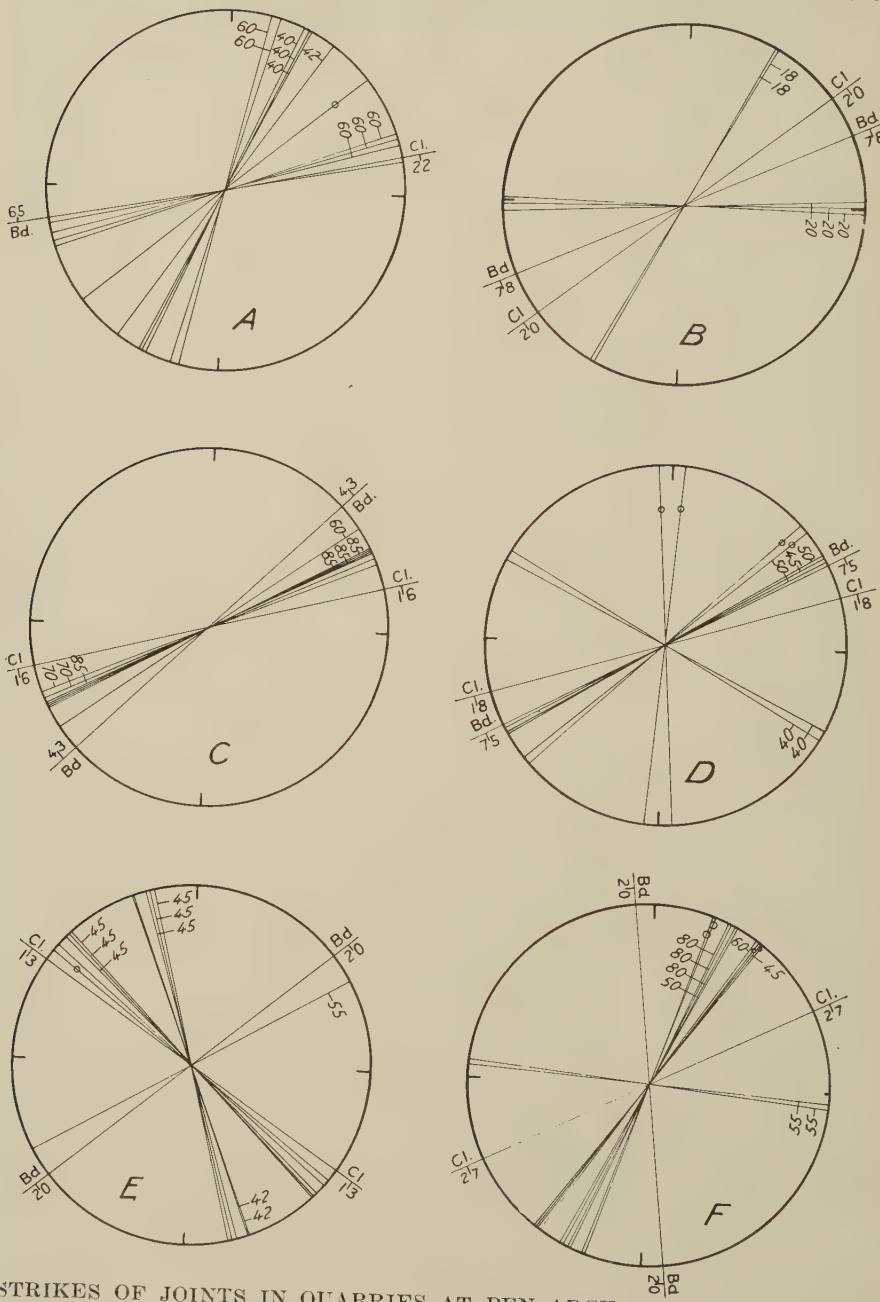
These folds appear to be parts of a large structure, a syncline whose axis lies well north of the town of Bangor. The syncline thus defined has a pitch that is westward, the axis emerging at the Shimer, Consolidated No. 3, and Mountain View quarries. This fold may, in turn be only a larger drag fold on a still larger synclinal unit, but evidence for such an interpretation is still lacking as the beds are covered northward by younger formations.

Very probably the beds in the Hoboken and New York quarries are similarly parts of a syncline, the axis of which is emerging, as the strikes are almost due north and the dips gentle and westward.

The dip of the beds in the quarries of the Bangor group is gentle and the structures either strike northeast (more commonly) or northward (if the opening lies close to an emerging axis). The cleavage planes generally strike northeast, roughly paralleling the bedding planes, but where axes emerge the strikes of cleavage and bedding intersect. The grain is uniformly northwesterly in trend.

Jointing was studied in detail in this group of quarries. All joints of thirteen of these quarries have been mapped in detail in azimuth circles. In a few quarries the joints radiate so as to fall in all points of the compass and generalizations in these instances become impossible; such quarries are always located on the ends of pitching troughs or on minor folds whose axes lie transverse to the strikes of the larger structural features. In most other cases generalizations in regard to joint strikes are difficult to frame. Two types of joint patterns may be recognized. In one the strikes of the greater number of joints form small angles on either side of the bedding strike; since the beds generally strike northeast, the joint strikes form an obtuse angle toward the southeast; this pattern is well illus-

PLATE XVII



STRIKES OF JOINTS IN QUARRIES AT PEN ARGYL, WEST BANGOR, AND NORTH BANGOR.

Bd, bedding; Cl, cleavage; numerals indicate angle and direction of dip.

A. Jackson Bangor No. 5. B. Jackson Bangor No. 6. C. Hercules. D. Northampton. E. New Peerless. F. New York.

trated in the Columbia Bangor, New Bangor, and North Bangor quarries. The second type is exemplified by the Bangor Union and Northampton quarries. In these cases, the intersections of the joints form acute angles toward the southeast. Intermediate are such patterns as those of the Bangor Central and North Bangor No. 3 quarries. In general it seems, thus, that the strikes of joints nearly parallel the bedding strike or are almost if not quite, at right angles to it. This general correlation suggests that the joints owe their origin to the same thrusts to which the folds are attributable. However, the occasional turning of cleavage at joints, their calcite or quartz filling, and the relations of some joint systems to bedding-slip faults that are clearly later than the folding of the slate, —these and other considerations compel recognition of the fact that jointing is generally of later date than the folding of the slate. The apparent relation between the joint patterns and the folding is perhaps best explained by the similarity in the direction of the two separate thrusts which produced the folds at one time and the joints later.

The products of the quarries of the Bangor group are varied. They include roofing slate, structural slate, blackboards, electrical slate, slate for "marbleizing," school slate, and crushed and pulverized slate. The outstanding product of the quarries of the Bangor group is roofing slate. Structural slate is of some importance, and electrical slate and blackboards less so, but most of the trade of all quarries excepting the New York and Northampton is in roofing slate.

The number of operating quarries is twelve. This district vies with that surrounding the town of Pen Argyl for position as the leading slate region in Lehigh and Northampton counties.

As in the case of the quarry descriptions for the Slateford group, the number appearing before the name of a quarry corresponds to that given on the quarry location map. The exact location of any quarry can thus be obtained with facility.

1. NEW YORK QUARRY

Location and dimensions.—This quarry lies approximately 2.8 miles north and about 5 miles east of the city of Bangor; it is three-tenths of a mile northwest of North Bangor station on the Lehigh and New England Railroad. Its dump is a conspicuous landmark.

The opening at the surface is roughly 280 feet long on a bearing running N. 60° W. The maximum depth is 190 feet; there is only a small amount of water at the bottom. The work is confined to one level.

Geology.—This quarry shows beds dipping northwest at moderate to gentle angles. At the surface along the south end the dip is 30°, with a flattening to 22° toward the north. In the bottom of the quarry the dips are 19-25°. A remarkable feature is the unusual strike of the beds, which bears almost due north. This feature corresponds to a

more northerly strike also at the Hoboken quarry. Taken by and large this suggests that the New York quarry is opened along the axis of a westward plunging fold. If the Bangor Vein quarry is in beds of the North Bangor No. 3 "run", it seems quite probable that the beds of the New York quarry are somewhere above the Albion "run" of the Pen Argyl beds. Without measuring, confirmation is lacking.

At the surface the cleavage could not be measured, but on the working level it trended generally N. 60-70° E., and dipped from 23-34° S. The grain strikes N. 48° W. The quarry has one very regular system of joints which strike N. 20-35° E. and dip from 60° to 90° N. Small joints, apparently associated with slippage (see below) are seen in the east corner and strike generally due east, with southward dip. A single very prominent N. 36° E. joint carries on from the working level all the way to the surface, dipping 45° S. (See Plate XVII, F).

Near the middle of the quarry two calcareous beds, about 4 feet apart in actual thickness, show heavy mullioning on the face of each; the striae trend N. 40° W. The heavy "rolls" developed by the movement have their steeper sides toward the north; hence it is clear that the top beds have moved up, the lower beds down, along this bedding plane, which has served as a plane of movement. The lower calcareous bed is cut by the southwest quarry wall, and clearly shows slice-like fracturing; each section or slice has, at its south end, been pushed up over its neighboring slice to the south. Nevertheless, the slate beds immediately above and below show no distortion except for a slight steepening in the angle at which the cleavage intersects them (see Plate VIII, A). This suggests that there has been relatively little movement since the cleavage was formed. However, just above the upper calcareous bed are stringers of quartz and calcite dipping obliquely southwest; these show that some movement has taken place either during or subsequent to the development of cleavage, a movement not taken up in the growth of the sericite flakes and therefore occurring not earlier than the later stages of sericitization; the fact that most of the joints stop at one or the other of the calcareous beds mentioned, supports the same conclusion. In short, it is evident that there have been two periods of movement, one in which the calcareous beds were folded and fractured and the clayey material (which today is slate) simply flowed around them; the second in which the clayey material, having been converted into brittle mica, was pulled apart by internal stresses and developed joints and quartz-calcite-filled fractures.

These two calcareous beds are good examples of the "loose ribbons" so often met with in the soft belt quarries.

Only one big bed, which is about 6 feet long along the "split"

(cleavage) was seen; this has, at the south a "hard roll" (sandy layer) which measures 18 inches along the "split."

It is thought that the movement permitted along the calcareous beds mentioned above served to relieve the strain, and that jointing should be relatively negligible below the lower of the two beds. This should enhance the value of the quarry.

History and development.—This quarry was opened in about 1885 by Solomon Flory. It was sold, after a short period of operation, to H. R. Brooks of Brooklyn, N. Y., who continued work until about 1895 when he leased the property to David Stoddard and John Bennett. Stoddard and Bennett quarried slate for five years; the lease was then transferred to N. A. Litchfield and Wm. H. Kirtland, who operated the quarry until 1909. Operations were stopped in that year, but in 1911 the property was purchased by Thos. Bolger of Bangor, then owner of the Woodley Slate Company. After incorporation, the company acquired the title to the property; the controlling interest is held by Thomas Bolger and James H. Bolger. Its value in issued shares is $60,000.

At present a well furnished mill is operating on the property. The equipment consists of five saws, four planers, two rubbing beds, a carborundum wheel, a drill press, and a Vermont-type buffer. Three cables are thrown across the quarry.

All types of slate products have been made here in the past, but at present the yield is confined to milled stock, including electrical slate and structural and sanitary material.

2. HOBOKEN QUARRY

Location and dimensions—The Hoboken quarry is about two miles north of Bangor, and about three-tenths of a mile northwest of Martins Creek. It is within 900 feet of the Lehigh and New England Railroad and about three quarters of a mile west of North Bangor station.

The opening measures 135 feet in a direction about due north by 100 feet along a N. 70° W. bearing. Water fills the quarry to within 15 feet of the surface, but the size of the dump suggests that the quarry is 60 feet deep.

Geology.—The slate has an overburden of six feet of glacial boulders and rounded gravel. In the northeast corner the beds strike N. 25° E. and dip 17° NW.; in the southeast corner the strike swings more easterly, being here N. 35° E., with a dip of 20° NW. It appears that these beds are on the under limb of a syncline overturned to the north. In what part of the Pen Argyl beds they lie is uncertain; it seems probable that they are slightly higher than the strata quarried at the New York quarry; they may, however, be about the same beds, here trending more nearly in their normal direction. One large bed

shows on the eastern side of the quarry, about 3½ feet thick. The cleavage strikes generally N. 65° E. and dips 40° SE. Grain trends N. 45° W. and is constantly vertical.

Only one conspicuous joint was seen; this strikes N. 10° W., and dips 70° NE.

History and development.—The quarry is said to be the property of Mr. J. F. Houck of Stroudsburg, Pa., but no information in regard to its earlier history could be obtained. It has evidently not been operated in the last ten years.

Two cables are still thrown across the hole. A long-unused mill, apparently once fairly well equipped with planers, saws, and one rubbing bed, stands south of the quarry. There are also the usual hoist houses. No shanties were to be seen, suggesting that little roofing slate was produced, although some was observed on the dump.

3. STRUNK QUARRY

Location and dimensions.—This and the New Peerless quarry are on opposite sides of the road leading to the mill of the New Peerless (Bangor Vein) quarry. They are about 2.3 miles from Bangor and 1.3 miles due north from East Bangor. The two openings are 150 feet apart.

The Strunk or Peerless quarry measures about 150 feet northeast by 220 feet northwest. It is 45 feet deep to water level and probably extends about 35 feet below water.

Geology.—The slate here is covered with 3 to 12 feet of glacial till.

In the southeast wall the beds are tightly folded and show minor crumplings along and parallel to the axis of a syncline overturned toward the north, whose axial plane strikes N.85°E. and dips about 13°S.; this axis pitches westward and shows again in the New Peerless quarry.

The thickening and thinning of beds is well shown in this fold (see Plate XVIII), as is also the effect of the emergence of an axis on the direction of dip of beds; thus at the surface in the western corner, the beds are vertical, but only 15 feet below the surface they are horizontal; in the southern corner, on the other hand, the strata dip 15° or less to the south on the upper limb of the fold; in the eastern corner the dip is opposite or 20°N.

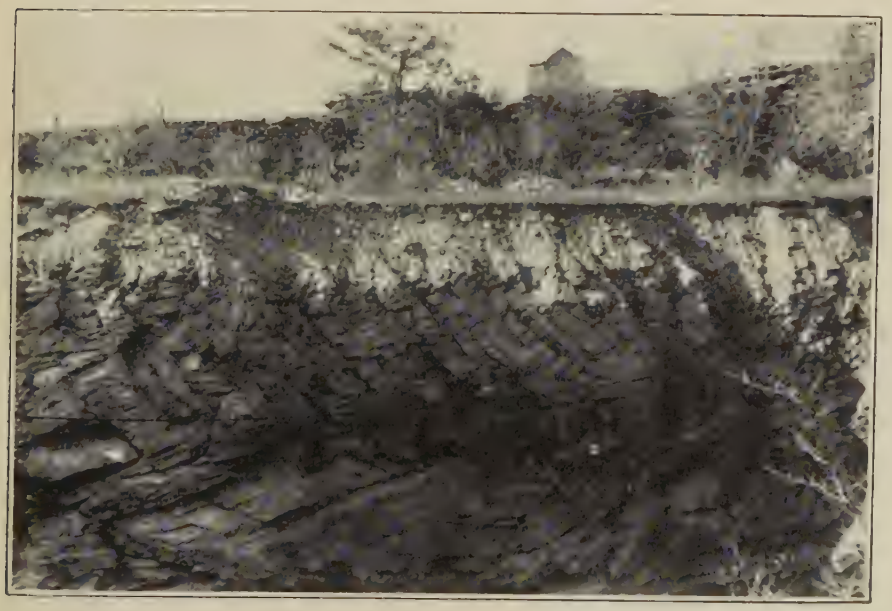
One big bed about 20 feet below the surface is to be seen in the middle of the southeastern wall. The same beds are exposed here as in the Peerless quarry.

The cleavage strikes about due east and dips 15°S. The grain appears to trend N.35°W. and is vertical, to judge by the quarry walls.

One prominent joint, striking N.48°E. and dipping steeply south, was observed. Similar jointing is to be seen in the New Peerless quarry.

PLATE XVIII

A. Southeast wall of Strunk quarry, looking S. 80° E. from the southwest side. Shows folding along axis of Peerless syncline.



B. Southwest side of Strunk quarry, as seen from near the east corner of the southeast side. Shows the close syncline also seen in A, above.

History and development.—The quarry is on the Strunk property, the line that separates this from the Peerless property being approximately the southwestern side of the quarry.

This opening was probably first worked in 1890, but the quarry has not been operated for a long time, presumably not since 1900.

A single cable is thrown across the pit. No other machinery remains.

4. NEW PEERLESS (BANGOR VEIN) QUARRY

Location and dimensions.—The opening is 200 feet west of the Strunk quarry (see above). It measures about 460 feet in a S.45°W. direction by roughly 225 feet in a N.50°W. direction, with lesser shoulders of rock jutting into the quarry near its southern corner.

The quarry shows two levels or "pieces". The bottom level is 120 feet below the surface of the ground. A higher level in the western corner of the opening is not at present worked. A pump is used to keep the quarry free from water. The large dump is north of the hole.

Geology.—In opening the quarry glacial drift was passed through, the maximum thickness being eight feet at the northeast side.

The slate beds in this quarry are thrown into a beautiful synclinal fold, having a northward overturn and an axial plane dipping here not more than 8° to the south, and striking about N.80°E. This axial plane, which is the same as that described in the Strunk quarry, seems to pitch 6° toward the west, as the synclinal axis appears only about 15 feet below the surface in the southern corner of the Strunk, 60 feet below the surface on the northeastern wall of the New Peerless and 100 feet below the surface on its western wall.

The beds record this structure quite clearly. In the upper level, about 60 feet below the surface, they strike N.45°E. and dip a maximum of 25°S.; in the lower level they strike similarly and dip a maximum of 60°N. (see Plate XIX).

The beds in which this quarry are opened are probably the same as those of the North Bangor No. 3 quarry, popularly known as the North Bangor No. 3 "run". In the classification here employed they lie a short distance up in the upper portion of the Bangor beds. This is the correlation generally accepted by slate operators, and as it appears to fit in well with the structure as worked out in these studies, it is here accepted.

A detailed measurement of the beds is graphically summarized in the columnar sections (Plate XIII). Two very thick beds are worked in the lower level; both have a "length" along the cleavage ("split") of 16 feet, including the hard south end; their actual thicknesses are 15 feet in the case of the upper (more northerly) one and 16 feet, 8 inches for the lower bed. The upper bed, with a hard roll 30 inches thick at its base, shows in the channel-cut southeast face of the upper level; the hard roll is interesting because it shows so

clearly the roughened top surface; it has already been described under the discussion of primary structures in the section dealing with the geology of these deposits (see Figure 5, C). This is the bed that is thought to be the equivalent of the North Bangor No. 3 First Big bed.

In this quarry the cleavage strikes N.80°W. in the upper level and near the surface, dipping 13° southward; but on the lower piece the strike is N. 20-47° W., and the dip is 12-14° SW. The anomaly in having cleavage strike so widely varying from the axial plane of the fold is not explicable, unless it be attributable to the disturbance caused by the bedding-slip fault mentioned below. As is usual, the cleavage curves somewhat as it crosses the thicker beds; this is noticeable in the photograph of a large block from this quarry (see Plate XI, A). The grain trends N. 40-47° W. and is vertical.

Jointing falls into two systems. One of these has an average strike of about N.30°W., with 45° dips to the north; the second has steep dips, within a few degrees of vertical in either direction, and strikes N. 55° W. Joints of the latter system are more common at the surface, and resemble the jointing seen in the Strunk quarry. A prominent N.33°E. vertical joint forms the northwest wall of this level at the surface, and a similar joint forms the southeast wall (Plate XVII).

The most striking structural feature in the quarry is a bedding slip fault; this type of structure has been described under "Faults", the section on detailed structure (see p. 66). In the tight fold already mentioned as showing on the northeast side, the more southerly beds have been far more closely folded than those to the north. In the intense shear between these two sets of beds, a portion of the more southerly beds have been completely sheared off (see Plate XIX). The fault zone has been shattered and is largly filled with quartz; a series of small joints, striking N.60°E. and dipping vertically appears immediately above the fault zone; along it, also, the cleavage is very highly flexed. The fault disappears westward, where the folding of the southerly beds is not so sharp. From this it would seem that working westward in the quarry would carry the operators out of this undesirable shear zone and into less closely crumpled beds, having a uniform southerly dip.

History and development.—This quarry is on the Peerless property. It was first worked by a partnership consisting of Jas. Masters, Wm. Blake, and E. J. Johnson of Bangor, Pa., having been opened about 1892. In 1895 the partners incorporated under the name of the Bangor Peerless Slate Company. In 1911 E. J. Johnson assumed full control of the management. The company leased the quarry in 1916 to the Bangor Vein Slate Company which continues to operate, with various changes in the controlling interest, until to-day.

The equipment includes a small mill, provided with saws, planers,

PLATE XIX

A. North half of northeast wall, New Peerless (Bangor Vein) quarry, showing relatively open fold of beds north of bedding slip fault. Compare with B.

B. South half of northeast wall, New Peerless quarry, showing close fold of beds south of bedding slip fault. The fault zone i self is highly shattered at A, but a closely folded bed shows south of it.

rubbing beds, and a Vermont type of buffer. The blocks are handled by a grapple swinging from a boom.

An interesting feature is the use of drilling and broaching in this quarry. This method of quarrying slate has been described by Bowles.[103] It consists in drilling holes three-quarters of an inch or one inch apart and later breaking out the slate between the holes with a broaching tool. This method saves slate, because it does not shatter the rock far out from the drilled hole.

The company makes and sells millstock, blackboards, and roofing slate. A specialty is the making of large quantities of small sized roofing slate.

5. LITTLE BANGOR QUARRY

Location and dimensions.—The opening is 500 feet south of the Old Peerless quarry, on the eastern side of a secondary road that leads from the ridge road at the south toward the Peerless property.

The quarry measures 45 feet square, its sides trending northeast and northwest. It is about 28 feet deep to water level and, to judge by its dump, may extend 15 feet deeper.

Geology.—The quarry should be in beds of the upper part of the Bangor Union "run", or in the lower part of the upper section of the Bangor beds.

The beds and cleavage are not clearly separated and appear to be about parallel, the cleavage dipping gently southward. Grain trends N.35°W. and is vertical. Two sets of joints are recognized trending respectively N.20°E., with dips of 80°NW., and N.55°E., with dips of 65°NW. These correspond to two similar systems in the New Peerless quarry.

History and development.—This hole, opened by a Mr. Wickett of Bangor about 15 years ago, is on the Bangor Peerless property. It has not been worked for the last ten years.

A mast still remains standing with its cable, and a small engine-house is on the dump. A little rather knotty roofing slate is to be seen. One or two blocks of slate 5½ feet long show excellent cleavage surfaces.

6. QUARRY

Location and dimensions.—This is a small cut about 250 feet east of the intersection of the ridge road with the road leading northwest from East Bangor. The prospect measures 45 feet N.40°W. by 25 feet N.60°E. and is 10 feet deep to the water level, but may be another 10 feet deep below the water.

Geology.—There is about 1½ feet of glacial overburden. Near the southeastern end one large bed, about 2½ feet thick, strikes N.35°E. and dips 20°N. There are also several sandy, somewhat calcareous

[103]Bowles, O.: Technical progress in slate mining: Eng. & Min. Journal-Press, vol. 117, No. 15, p. 606-607, 1924.

layers. The cleavage is virtually horizontal. The grain apparently trends N.40°W.

The flat cleavage in this quarry suggests the presence of another close fold toward the north.

7. MOUNTAIN VIEW QUARRY

Location and dimensions.—This quarry lies on the western flank of a small valley about 4,000 feet due north of East Bangor, 1,000 feet south of the ridge road, and 1,500 feet northeast of the Consolidated No. 3 quarry. It measures approximately 150 feet N.45°W. by 100 feet N.70°E., but opposite sides are not parallel, so that the opening is irregular in shape. The maximum depth of the quarry walls is 20 feet to the water level, but it is probably an additional 50 feet deep below the water. The dump, shanties, and factory remnants lie to the south.

Geology.—The slate in this quarry bears a glacial overburden one to three feet thick, consisting of clay and boulders of all sorts; some boulders are well rounded, others are facetted and even striated.

The strike of the bedding is N.35°W., with a dip of 9° toward the southwest. As the next outcrops to the north of this quarry show strikes that are again northeast and more nearly normal, it would appear that this opening is near the axis of a westward pitching syncline.

A single large bed about 2 feet thick with a "hard roll" a foot in thickness outcrops 10 feet east of the southwestern edge of the quarry. The beds worked here were probably those immediately above and below the Gray bed of the Old Bangor "run", although those exposed at the surface are all slightly higher.

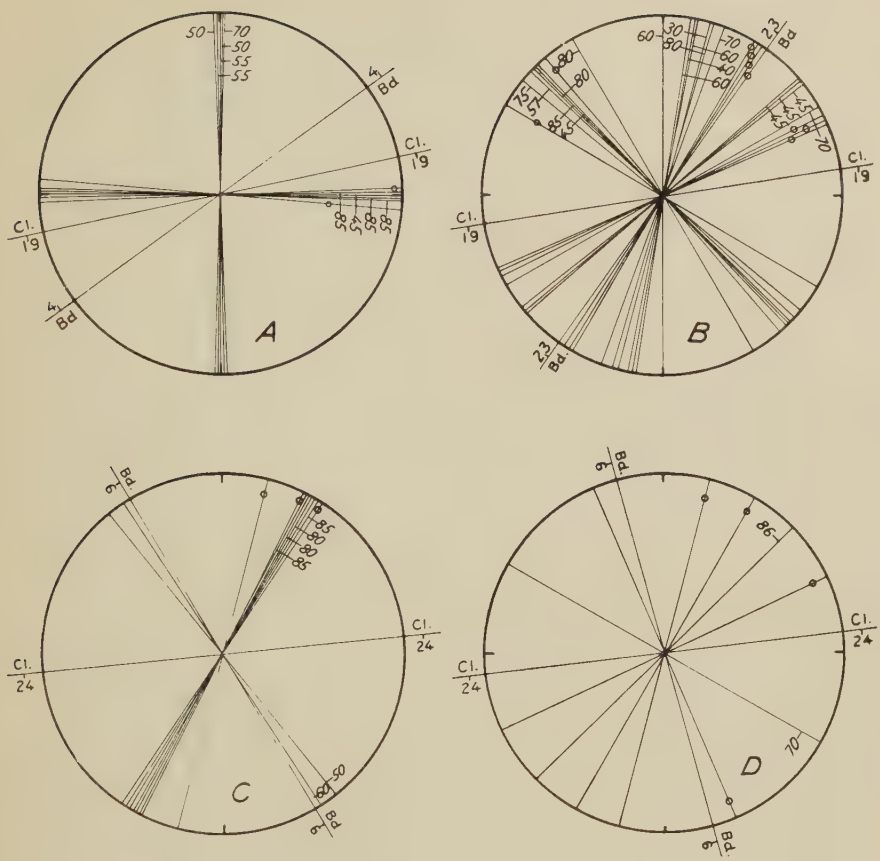
The cleavage strikes N.75°E., dipping 20°S.; the grain trends N. 45°W.

A series of joints with N.45°W. strike, dipping 55°N.E., is prominent; in the western corner is a vertical joint striking N.20°E.; on the southwestern side are several vertical joints averaging N.60°E. in strike. The radiating pattern of these joints, so characteristic of openings on the ends of axes (see also the description of the Consolidated No. 3 quarry, and the joint diagrams, Plate XX) is here well shown.

History and development.—Nothing is known of the history of operations at this opening. It has probably not been worked in the last ten years.

One mast and cable are yet in place. Engine, hoist houses and boiler room are still standing. Four shanties are on the dump. Old, badly rusted tracks are also to be seen.

The products included milled material and roofing slates.



STRIKES OF JOINTS IN QUARRIES AT EAST BANGOR

A. Bangor Central. B. Consolidated No. 1-Star. C. Consolidated No. 2. D. Consolidated No. 3. Symbols as in Plate XVII.

8. CONSOLIDATED NO. 3 QUARRY

Location and dimensions.—Approximately 2,000 feet northwest of the town of East Bangor, in the direction of the ridge road, is an irregular opening, roughly rhomboid in shape, measuring approximately 400 feet in a northeastern direction by 300 feet toward the northwest, but with its southeastern side shorter than its northwestern one. The quarry is now worked on two separate levels or "pieces", both lying along the northwestern side, the eastern being 50 feet and the western about 40 feet below the surface. The deepest part of the hole, now partially filled with waste, is along the southern edge.

The quarry dump is mainly along the southeastern side of the opening, but waste has also been thrown directly into the abandoned deeper portions of the quarry.

Geology.—In detail the strike of the beds in this quarry is variable, extending from N.8° to 25°W., with dips of 5° to 8°W. The major

structure, like that in the Mountain View quarry, is a pitching syncline with a somewhat flat bottom, and it would seem that this quarry is nearer the axis, which has a 25° pitch westward. The Gray bed lies 50 feet below the surface along the northwestern wall of the quarry. This shows that the opening is in the upper of the two sections of the Bangor beds. In the northwest wall of the quarry is the Black Ribbon big bed; about 18 feet below the surface of the ground and on the floor of the upper piece is the Thirteen big bed, which here has a thickness of 3 feet and a "length" along the cleavage of 8 feet.

The cleavage in general strikes N.85°E. and dips 24°S.; grain trends about N.57°W.,—which is unusual.

The jointing in this quarry is significant. The systems are numerous and the general pattern is radial (see Plate XX). The following is a list of the joint strikes and dips actually observed:

Joints in Consolidated No. 3 quarry.

Strike	Dip	Number	Strike	Dip	Number
N.15°E.	Vertical	3	Due E.	35°S.	3
N.30°E.	Vertical	1	N.60°W.	70°S.	3
N.46°E.	86°N.	1	N.50°W.	Vertical	2
N.50°E.	Vertical	1	N.22°W.	Vertical	1
N.65°E.	Vertical	1	N.22°W.	80°N.	2

It follows from the above that every thirty degrees in azimuth have their joint or set of joints. Of these, the joints striking due east may well be compression joints, developed by the inward pressure toward the axial plane exerted by the limbs of the fold.

History and development.—This quarry, according to the owners, was first opened by them in 1882. It is now the property of the East Bangor Consolidated Slate Company, Inc., of East Bangor, Pa. The history of this business organization is described in connection with the Consolidated No. 1—Star quarry.

The quarry has three cables. The owners operate a mill the equipment of which includes six saws, three planers, and a rubbing bed. The machinery is driven by two shafts, the power being linked to one shaft, which then has a connecting belt to the other shaft,—a common arrangement in slate mills. In addition a central shaft is linked to the first and drives the rubbing bed and a rip-saw opposite. The blocks in the mill are handled with a boom and grapple.

Two shanties were in use when this quarry was visited.

The products are roofing slate and slate for structural and sanitary purposes.

9. SHIMER QUARRY

Location and dimensions.—The quarry lies about 300 feet northwest

of the Consolidated No. 3 quarry. It is 300 feet long, 175 feet wide and roughly rectangular. Only 25 feet of slate at most show above the water, but the quarry is probably 75 feet or more deep below the water surface. The dump lies across the road to the west.

Geology.—There is an overburden consisting of ten feet of glacial boulders and weathered slate. The slate below this is inaccessible; hence only estimates of the dip and strike of the beds could be made; these appear to be N.40°W., 15°SW. The quarry is therefore in the same synclinal trough occupied by the Consolidated No. 3 and the Mountain View quarries, and operations were probably in much the same beds, the Gray bed having probably a depth of 40 feet below the surface.

History and development.—This quarry has been idle for several years. The cables are rusted and the timbering badly decayed. Two hoist houses are on the southeastern side of the hole. The mill and the main dump are across the road, west of the quarry. The remnants of millstock on the dump look promising; no roofing slate was seen, but some was undoubtedly made here.

10. CONSOLIDATED NO. 2 QUARRY

Location and dimensions.—The quarry is 500 feet southwest of the Consolidated No. 3 quarry and lies between that opening and the Consolidated No. 1—Star pit. A line due north from the southern corner of the opening would cut its northern corner. The quarry is almost rectangular, but the southwestern side is only 250 feet long, while the southeastern side is 400 feet long and each of the other two sides measures roughly 300 feet. The hole is 70 feet deep to the level of the water which stands in the deepest part. A large dump is built up along the southeastern edge.

Geology.—The overburden is stripped back from the sides of the quarry. The beds are like those of the Consolidated No. 1—Star, but the strike has taken a sudden turn, so that it is N.40°W., with a dip westward in the western corner at the surface, although lower down the strike is N.30°W. The quarry is thus still in the synclinal trough mentioned in the description of the Shimer, Consolidated No. 3, and Mountain View quarries.

The cleavage here strikes N.85°E., and dips 23° (average) S. The grain trends N.40°W., dipping 70°-90°N.E.

Jointing is conspicuous. Two sets of joints are recognizable,—one striking N.15°-35°E. and having very steep dips, the other striking N.35°W. (average), with dips of 50°-60°N. The strikes are very similar to the two main systems in the Consolidated No. 1—Star quarry, but the angles of dip are different (see Plate XX).

History and development.—The quarry site was located by Bray and Short in 1865; 110 acres of land around this quarry were bought

for $6,000. At the time the opening was made, it was known as the East Bangor quarry. Operations were conducted by Bray and Short until 1882, when the East Bangor Consolidated Slate Company, with capital stock valued at $250,000 formed to work both the Consolidated No. 1 and Consolidated No. 2. For the history of this company, see the history of the Consolidated No. 1—Star quarry.

The millstock from this quarry was sent to the mill at the opening of the Consolidated No. 1—Star. The roofing slate was handled on the dump to the south in shanties, eight of which are still standing. Three masts served the quarry. The production consisted of structural and sanitary material and roofing slate.

11. CONSOLIDATED NO. 1—STAR QUARRY

Location and dimensions.—The large dump of this quarry is a conspicuous landmark at East Bangor. In area of surface opened, the quarry is the second largest in the district. It is irregular in form suggesting a rectangle 500 by 1,000 feet in size, and having its longer dimensions extending about N.55°E., but with a triangular promontory of slate projecting northward from the southern corner. The bottom of the quarry is extremely variable in depth, as the opening has been worked irregularly, now here, now there. At present two working parts are maintained, one in about the middle of the southeastern, the other midway along the northwestern side. Of these the southern is 60, the northern 80 feet below the surface.

The dump almost completely surrounds the opening. It is built up mainly, however, along the southeastern and northwestern sides; much of the waste has been thrown into the old hole.

Geology.—A difficulty encountered in stripping the northern part of this quarry was the large quantity of glacial material overlying the slate. This overburden is 20 feet thick along the northwestern side of the quarry near the western corner, but thins to only three feet toward the south and decreases similarly eastward. Plate XXI, A, illustrates the heavy cover which must be stripped off before the slate is reached. The northeastern corner of the hole shows no glacial overburden,—merely 5 feet or so of weathered slate that has to be stripped before solid rock is met.

Below the surface, after the beds to the south take a sharp turn, so as to dip southward at a steep angle (see description of Columbia Bangor quarry below), they resume a northward dip, which seems to flatten more and more as the beds are followed down the dip. It is these north-dipping beds that the Consolidated No. 1—Star quarry has exposed. These strike variously, an average of five observations along the southern working piece giving a strike of N.32°E., with a dip of 21°N.; the dip, however, suffers minor variations, in general declining northward, while the strike swings more nearly due north,

PLATE XXI

A. Northwest wall of western part of Consolidated No. 1-Star quarry, as seen from west corner of opening; shows 25 feet of glacial overburden.

B. Dump of overburden from Columbia Bangor quarry; material is thrown into the abandoned part of the opening.

so as to become N.20°W. at the most northerly corner of the hole, with a dip of 7°SW. In short, the structure presages the westward pitching synclinal axis mentioned in the Shimer, Mountain View, and Consolidated No. 3 quarries. A sketch map to show these changes in dip and strike is presented in Figure 30. The beds quarried are mainly those lying immediately above the Gray bed, which is itself to be seen in the southern working level, and outcrops again just south of the southeastern edge of the opening at the surface of the ground. The

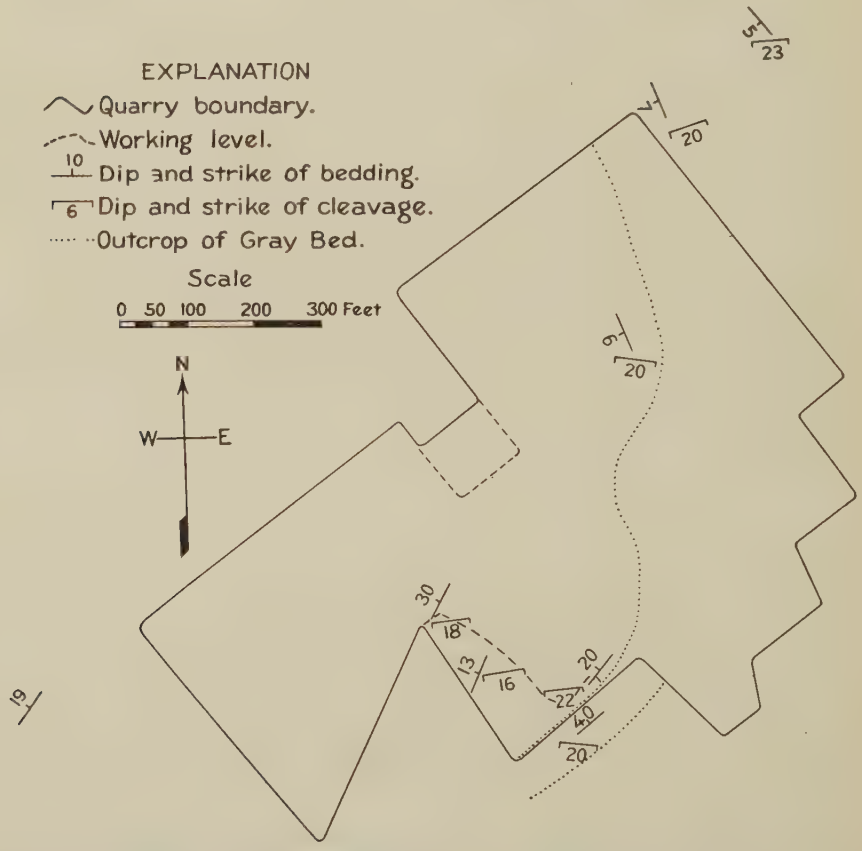


Figure 30. Sketch map of Consolidated No. 1-Star quarry, to show northward change in strike of beds as synclinal axis is approached.

Middle big bed should be not far below the present workings and accessible in depth. At the northern working level the Black Ribbon bed is being worked and the Bangor Union big bed shows in the southwestern wall of the quarry, west of the southern working level.

The cleavage shows slight variations in strike and dip, but may be generalized as striking N.80°E., with a dip of 19°S. The grain trends N.40°W., with a dip of 80°E.

Jointing is complex, as might be expected with the sharp turn of the bedding. In the Consolidated No. 2 quarry, the joints have been described as constituting two sets,—one striking N.15°-35°E., with steep dips, the other striking N.35°W. with northward dips of 50°-60°. In the Consolidated No. 1—Star quarry similar strikes are seen, but the dips are not the same, both systems having steep dips in either direction. Most conspicuous are vertical joints having strikes of N.30°E., which are especially well developed on the northeastern wall of the quarry (see Plate IX, B). A set of N.65°E. joints dip vertically, and generally ends at the intersection with joints of the N.35°E. set; it is suggested that the N.65°E. set is particularly related to the turn in the strike of the beds. These systems should also be compared with the joints observed at the Mountain View quarry (Plate XX).

In the bottom of the quarry, which is now covered with waste, and in the northwestern corner there are places where calcareous beds show minute crumpling with the development of false cleavage. Here quarrying will probably prove unfavorable, as the regularity of cleavage in slate bearing false cleavage is generally reduced.[104]

History and development.—This quarry originally consisted of two separated parts,—the eastern, formerly known as the Consolidated No. 1, and the western, smaller portion called the Star quarry. The eastern two-thirds of this quarry was opened by Bray and Short, then quarrying under that firm name, in about 1870, after the discovery by Short of slate on this property and his purchase of 110 acres for $6,000. The purchase mentioned was intended to increase the dump and facilitate operations at the Consolidated No. 2 (then known as the East Bangor) quarry, but after the discovery of slate on the newly acquired land, an opening was made on it. Bray and Short operated this hole as well as the present Consolidated No. 2 until 1882; at this time a company, the East Bangor Consolidated Slate Co., with a capital of $250,000 was formed to develop this and the Consolidated No. 2 quarry.

Since 1868 the old Star quarry, which is the triangular, most western portion of the present opening, had been operated by various persons,—at first by Major Ames of Portland, later by a group of eight Englishmen, and finally by the American Slate Company, which also owned the Bangor Southern and American Bangor. In 1919 the East Bangor Consolidated Slate Company bought this quarry from the Ayres Estate. Since that time the two openings have been united and operation of the resulting large quarry has been continuous. The present capitalization is $300,000.

The first slate mill was erected at the Consolidated No. 1 quarry in 1885-86. It has been continuously running in the same building. In

[104] Dale, T. Nelson.: Slate in the United States; U. S. Geol. Survey, Bull. 586, pp. 37 and 61, 1914.

the beginning one of the main products was marbleized slate. Now all types of structural and sanitary materials have taken the place of the more ornamental "artificial marble".

A diagram of the mill arrangement is given in Figure 31.

The power drives one shaft, which is linked by belts to all the machinery on the right side of the central track; a belt also links this shaft to a parallel one, by which the machinery on the left side of the mill is driven.

The small "rip-saws" used for the sawing of trimmed millstock (numbered 1 and 2 in the diagram) have extra small tables measuring respectively 5 by 7 feet (No. 1) and 3½ by 6 feet (No. 2).

An innovation is a small simplex crane with a chain hoist, on a crescentic overhead track; hand power is employed for its operation. A horse is used to haul slate along the track in the mill.

Two shanties at the mill make roofing slate of the rejects. In the

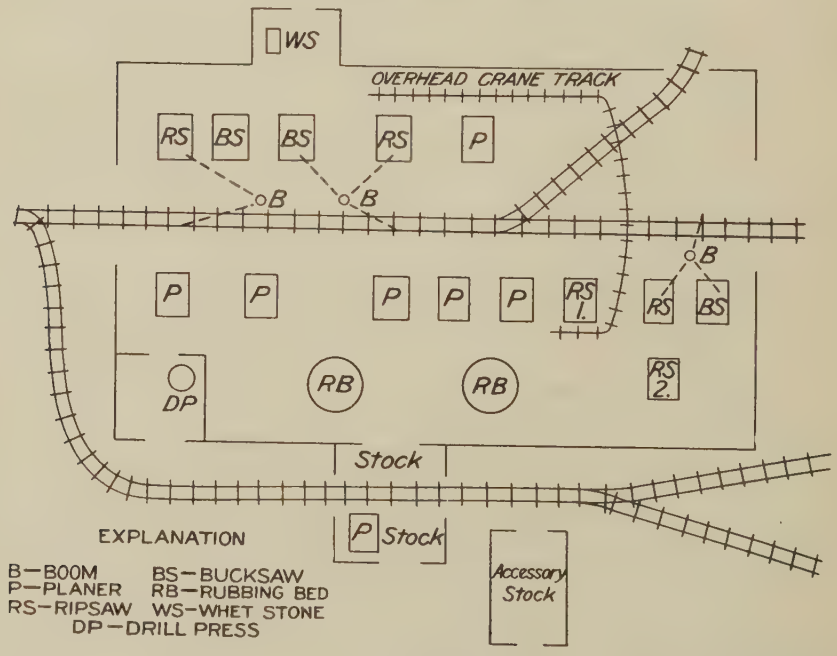


Figure 31. Plan of mill of Consolidated No. 1-Star quarry, East Bangor.

quarry, two cables run across the hole along the southeast side from just north of the east corner. Other cables are thrown across from the middle of the northwestern edge, where there is another landing and where most of the roofing is made.

The products now are roofing slate, structural and sanitary slate, and electrical slate. As noted, slate for marbleizing was once of importance.

12. STANDARD QUARRY

Location and dimensions.—This quarry is 200 feet west of the western corner of the Consolidated No. 1-Star quarry. It is 300 feet long in a direction about N.40°W. and 200 feet wide; its shape is irregular, being generally rectangular, except that the southern corner is acute, the eastern one obtuse. Water at least 50 feet deep fills the quarry to within 15 feet of the top of the slate.

Geology.—A moderately thick overburden shows on the southeastern side; it is here 5 feet thick and consists of a mixture of boulders set in a matrix of gravel and clay. The slate exposed reveals but little of its structure, but it can be safely assumed that the beds dip much as in the Consolidated No. 1-Star pit to the east. Near the northern corner the strata strike N.45°E. and dip 22°NW.; in the middle of the southeastern side they strike N.35°E. and dip 19°NW. No big beds are to be seen above the water level. The beds worked must, however, have been the same as those exposed in the Consolidated No. 1-Star quarry, except that the Gray bed was probably encountered at greater depth.

The cleavage strikes N. 78° E., and dips 21°S.

History and development.—No machinery remains at this quarry, and nothing was learned of its history.

13. BANGOR VALLEY (BANGOR ECLIPSE) QUARRY

Location and dimensions.—This opening is about 3,500 feet due west of the town of East Bangor and about 1,200 feet west and slightly south of the western edge of the Consolidated No. 1-Star quarry. It measures roughly 200 by 300 feet, having its longer dimensions in a northwesterly direction. Topographically it occupies a low position, the top of the hole being only about 30 feet above the creek. The ground rises to the north, however; at the northern end of the quarry, therefore, sixty feet of bed rock are to be seen above the water-line, while southward the slate exposure diminishes beneath a cover of glacial till until, at the southern edge, the glacial material itself passes below water. Probably the depth of the quarry was 100 feet.

A good-sized dump along the southeastern edge is confluent with that of the Bangor Central quarry toward the west.

Geology.—The cover is of unassorted, generally well rounded boulders and is 15 feet deep in the southern corner of the opening.

In the northern corner the beds strike N. 88° W., dipping 10° NE.; virtually the same dip and strike are observable elsewhere in the walls, Presumably the beds are about the same as those in the Bangor Central quarry (see below), but the upper sections of the latter are probably missing because of the lower topographical position of the Bangor Valley quarry. No thicker beds were seen.

In general, the cleavage strikes N. 59° E., and dips about 25° S., steepening slightly northward. Grain trends N. 45° W. and is vertical.

Two systems of joints were noted striking respectively N.55°E., and due east; the former system can be subdivided respectively again into joint planes dipping about 35° S. and others dipping 50°N. The joints that strike due east are vertical but are the less well marked of the two systems. These various types of joints are well seen on the northwestern wall.

History and development.—The quarry was formerly operated under lease by Messrs. Jacobs and Ford of Bangor. It was shut down at the beginning of the World War. Profit was especially obtained from quarrying the Mike Taylor bed.

The opening is on the estate of David Howell.

No machinery or slate stock were to be seen.

14. BANGOR CENTRAL QUARRY

Location and dimensions.—The quarry lies 200 feet west of the Bangor Valley quarry. It is a rather small hole, nearly square, with a length of 225 feet. It is worked on one level, which has a depth of 250 feet. The dump lies mainly along the northwestern side.

Geology.—The till cover, similar to that observed in the Bangor Valley opening, is as much as 25 feet thick, but it varies greatly.

At the surface the beds appear to dip 3° S., with a strike of N. 60° E. In the bottom, the dips are northward and generally 4° to 5°, with strikes averaging N.45°E. The structure is thus continuous with that of the western side of the Consolidated No. 1—Star pit.

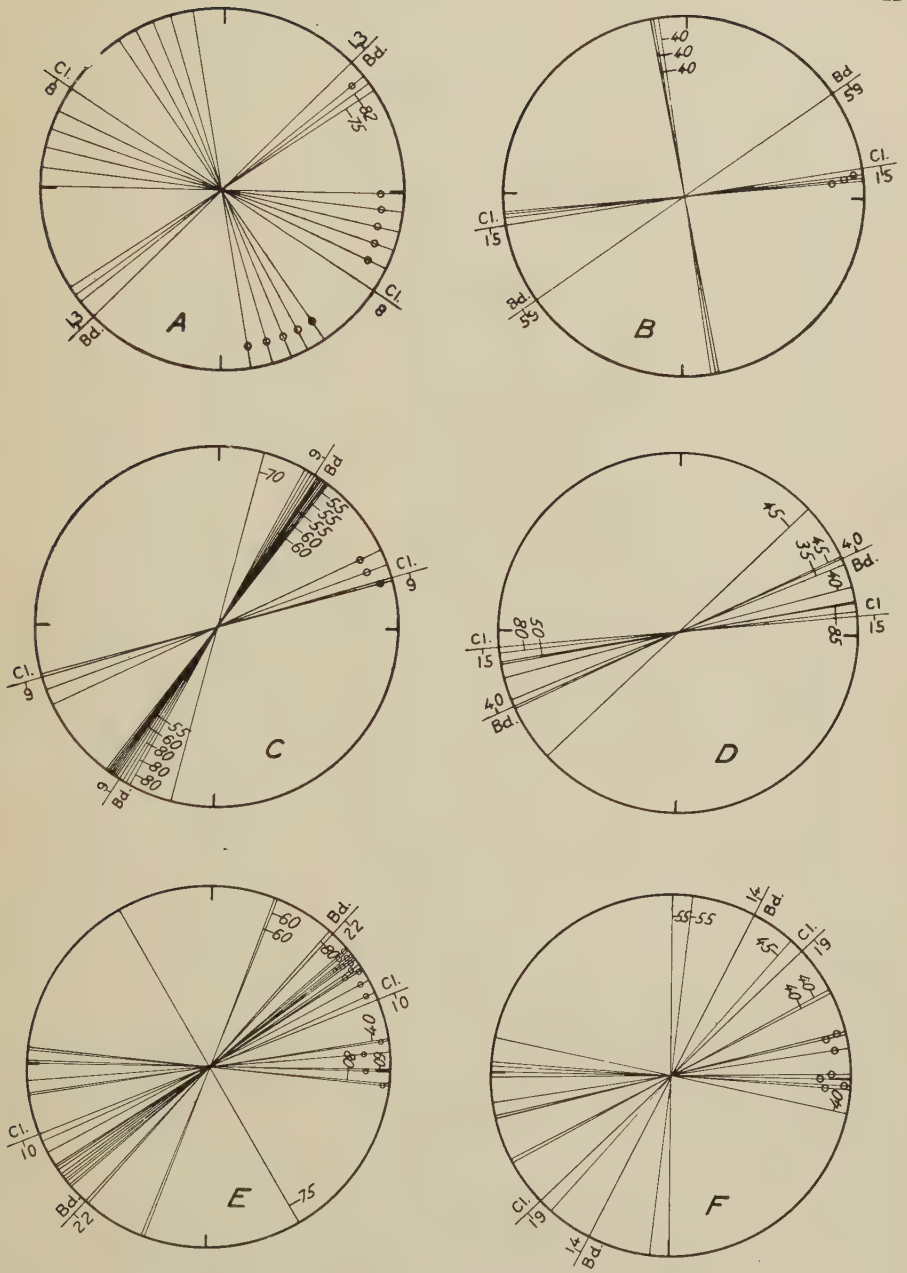
In the bottom of the quarry the sequence exposed is mainly that lying between the Thirteen big bed and Black Ribbon big bed; it is said that continued downward progress has exposed the Gray bed at the southern back of the quarry. In opening, the Mike Taylor big bed was cut through at the very surface.

The low angle between the dip of the beds and the dip of the cleavage is favorable to a considerable "length" of slate along the cleavage, even though the beds are somewhat thinner than usual.

The cleavage dips 30° or so SE. at the surface and has an average dip of 15° in the bottom, with a strike of N.80°E. Grain trends N.65°W., an unusually strong westward strike; the grain plane stands vertical.

Jointing in this quarry is exceptionally uniform. No observations of joints were made at the surface and it is possible that these might have been at variance with the systematic arrangement seen in the bottom of the opening. On the working level, however, only two joint sets were observed, of which one strikes due north, with dips of 50° or more, generally eastward; the other and dominant set strikes due east, with vertical dips. This constancy in joint systems is probably

PLATE XXII



STRIKES OF JOINTS IN QUARRIES AT BANGOR

A. Bangor Union. B. North Bangor No. 3. C. North Bangor No. 1. D. Columbian Bangor. E. Old Bangor, top piece. F. New Bangor.

attributable to the fact that the nearest close fold—that in the Columbia Bangor (see p. 156)—has a strike apparently at right angles to the direction of thrust in the slate folds, so that minor stresses with an oblique direction, such as would be exerted in the ends of pitching troughs, were not set up.

An interesting, though not exceptional, feature observed in this quarry is the presence of "water splits". These are a special type of incipient jointing along essentially horizontal planes (see p. 75).

In this opening also, the development of lenses of pyrite on the joint planes was observed. As far as can be recalled, these were seen only in the joints striking due north. They are thin in their east-west dimensions, measure 0.1-0.2 inches vertically, and are 0.3-0.4 inches long. They are clearly secondary. Such a lens is called a "knife" or "Jacky Hughes" by the quarrymen.

Hitory and development.—The quarry was opened about fifty years ago, but a period of depression forced the suspension of work about 1885. William Blake was prominently connected with the earlier operations. The quarry was opened again in 1906 by C. C. Wise of Bangor, under whose management it has produced slate continuously since then, with the exception of short periods during the World War or when the slate trade was slack. It is operated by the Bangor Central Slate Company, which is incorporated with bonds valued at $40,000, and stock having a par value of $25,000. C. C. Wise and P. F. Yetter of Bangor own the controlling interest. There is no mill for making sawed slabs. Boiler and engine houses, landing and masts, are on the northwestern side of the hole. The dump has been built up on three sides of the quarry, but most of the waste is now carried to the northern side of the dump, on which the landing is located.

The quarry is at present producing only roofing slate and wall slate, although millstock and electrical slate could well be made. Wall slate is slate cut and split into thick blocks and used as a filler and thermal insulator. In October, 1923, eleven shanties were making roofing slate.

A plant has lately been installed to crush and pulverize slate for use as blue-black and roofing granules; this is operated by a separate firm, the Bangor Central Slate Company furnishing waste from its dump under a working agreement.

15. BANGOR ROYAL QUARRY

Location and dimensions.—This opening, an elongated rectangle measuring about 350 by 150 feet, with its longer dimensions trending about N.40°W., lies 200 feet west of the Bangor Central quarry. It is now largely filled with water, the exposure of slate and overburden being thickest along the north side, where it reaches 48 feet. The open-

ing must have been at least 100 feet deep to the bottom, including what is now submerged.

Most of the dump is at the northwestern end of the quarry, but two lobes of waste extend northward from this along the quarry sides.

Geology.—On the southern edge the solid rock bears an overburden of 25 feet of glacial till, which diminishes to 8 feet northward; it consists of rounded boulders set in a matrix of sandy clay.

Beneath this at the northern end of the quarry 40 feet of slate are exposed. This slate is nowhere accessible, but its strike appears about the same as in the Bangor Central, with a northward dip of approximately 7°. The attitude of the cleavage is similar to that in the Bangor Central quarry. Grain trends N.45°W. and dips vertically. A description of this opening, appears in Sanders[105] report on the slate region; it is described as having bedding dipping N.40° E. and cleavage S.40°W., but it is believed that the letters were reversed in the printing, the beds actually dipping N.40°W., and the cleavage S.40°E.

No joints were definitely recognizable, although the northern wall bore a suggestion of a set striking N.60°E.

History and development.—Nothing could be learned of past operations. The quarry has been abandoned for at least ten years. It was evidently already opened when visited by Sanders in 1874-78. It was then known as the Bangor Old quarry.

16. COLUMBIA BANGOR-NEW BANGOR QUARRY

This opening is owned and operated by two separate companies. The eastern end is generally known as the Columbia Bangor (Ditchett's) quarry; the western end is now owned by a company which uses the name of New Bangor quarry.* For convenience the geology and history of the eastern of the two portions of the opening will be separated from those of the western section.

Location and dimensions.—The quarry lies along the southern side of the state highway between Bangor and Portland, and roughly a mile northeast of the postoffice at Bangor. It is 4000 feet westward from the East Bangor Hotel.

The opening is large and irregular in form. Measuring 800 feet in its greatest dimension, along a bearing of N.45°E., it has a width of 400 feet, and is the third largest opening in the Bangor group. The northwestern edge is straight, but the southeastern one is gently curved, with the convexity southward.

At the eastern end the quarry has a maximum depth of about 125 feet from the natural surface of the land. A second and higher level is, however, now being worked downward and the deep level has

[105] Sanders, R. H.: Op. cit., p. 91.

* In 1926, operated under the name of Bangor Ideal Slate Mining Company, managed by Jos. B. Trayes.

been abandoned. On the western end the depth is 100 feet, and the main present working level is only 25 feet below the surface of the ground, extending along the southwestern edge of the quarry. The hole is being slowly filled at the northeastern edge as well as at the middle of its northwestern edge by the strippings that are obtained as the quarry is extended eastward,—a process now going on.* As the land surface slopes northward, the quarry hole is deeper to the south.

The dump of the operations on both eastern and western ends is built up on the hill toward the south.

Geology of the Columbia Bangor (eastern) part of the quarry.— A heavy overburden of drift is encountered in this quarry. The opening is the only one in which a direct clue to the structure underlying that shown in the Old Bangor is seen. It will be recalled that in the Bangor Central opening the beds dip gently northward. These beds, as they are followed up dip and southward, make a sharp turn where they are cut by the northwestern wall of the Columbia Bangor. In the northwestern and northeastern walls, therefore, of the Columbia Bangor, there are shown the traces of a sharp syncline, the axial plane of which dips gently southward. Thus on the northeastern wall at the surface the beds dip steeply southward, but change the direction in their downward course until they dip northward at an

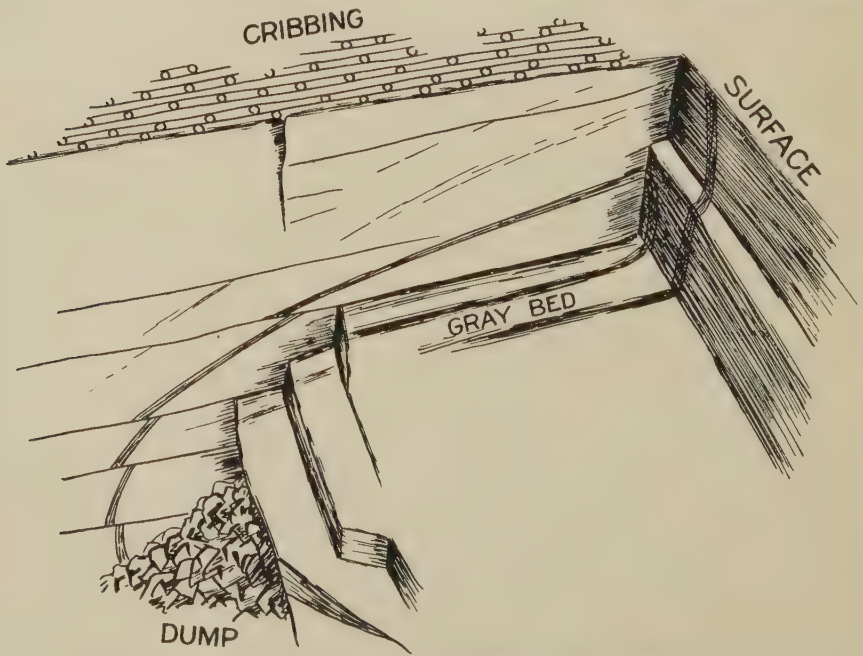


Figure 32. Sketch of north corner of Columbia Bangor quarry to show projection of bedding on northwest and true dip on northeast wall; as seen from near the east corner of the opening.

* See Plate XXI, B, p. 147. In 1926, the portion thus stripped was yielding good slate.

angle of 45°. The strike is N.65°E., and the bedding trace on this wall, which trends roughly normal to the strike, thus shows the true structure in the Columbia Bangor quarry. This fold passes into the northwestern wall of the quarry, however, under the dump. The projection of the bedding on the northwestern quarry face is thus a flattened curve closing westward. Figure 32 illustrates the appearance of this feature as seen when looking down into the northern corner of the quarry from the southeastern edge. As the structure is followed upward, however, it gives place to a very close anticline, the upper limb of which forms the lower limb of the Old Bangor syncline. The axis of the anticline is nowhere shown, but is inferred from a comparison between the syncline seen in the northeast wall of the Columbia Bangor portion of the opening under discussion and the southwest wall of the New Bangor, which shows only a part of its upper limb or—what comes to the same thing—of the lower limb of the Old Bangor syncline (see Plate XV, p. 108).

A study of Figure 25 C will explain the peculiar loop-shaped trace

Figure 33. Old Bangor syncline, viewed along the strike, as seen in northeast wall of Old Bangor quarry.

of the beds in the northwest wall of the Columbia Bangor quarry. The right side of the figure represents the true structure, as viewed in the northeastern wall of the quarry, while the left side shows the appearance of the trace of the fold on the northwestern quarry wall.

It is thus apparent that there are in this and the New Bangor portion of the quarry traces of two synclines and an anticline, all recumbent. The dip to be seen in the New Bangor end of the opening is the lower limb of a syncline with nearly flat axial plane and the upper limb of a small, sharply turning, northward recumbent anticline; the lower or north limb of the anticline is seen on the northeast wall of the Columbia Bangor quarry where the complementary underlying syn-

cline, which may be called the Columbia Bangor syncline, is clearly visible. This Columbia Bangor syncline may be regarded as a small drag fold on the under limb of the larger Old Bangor syncline to be mentioned later.

The beds exposed in the Columbia Bangor are the Gray bed and the sequence immediately to the south (i.e., below). The Middle (or Gray bed) big bed is to be seen in about the middle of the bottom of the Columbia Bangor portion of the hole. A remarkable feature is the great actual thickness of the beds. A comparison of the thickness of the Middle big bed in another quarry, lying off the line of strike is significant:

	Actual thickness	"Length" along cleavage
"Quarry A"	40 inches	121 inches
Columbia Bangor quarry	130 inches	144 inches

That this difference in thickness is not limited to the Middle big bed alone, but affects all the beds in or near the axis of the fold at the Columbia Bangor, is shown by these measurements of the Uncle Sam bed:

	Actual thickness	"Length" along cleavage
"Quarry B"	25 inches	46 inches
Columbia Bangor quarry	144 inches	162 inches

Neither "Quarry A" nor "Quarry B" has the great thickening of beds seen in the Columbia Bangor. The angle between the cleavage and the bedding in the last-named quarry, however, is so nearly 90° that the length of slate obtainable is scarcely greater than the actual thickness of the bed.

The cleavage in the Columbia Bangor quarry strikes N. 87° W., and dips 15° S. Grain trends N. 45° W. and is vertical.

The joints observed here have an average strike of about N. 60° E. and dip northward at angles of 45°; two vertical joints with about the same strike were also seen. A feature well shown in connection with the jointing is the presence of small minor joints and "wrinkles" along the course of the major joints (see also Plates X, B and XXII, D).

History and development of the Columbia Bangor part of the quarry. —This opening was formely included with the western portion and called the Howell quarry and is now frequently spoken of as the Ditchett quarry. It was already cleared to a depth of 80 feet in 1874-78[106]. It is situated on the Howell Estate. The quarry was opened in about 1870 by David Howell, then a resident of Bangor. Later it was leased to the partnership of Bowers and Mutton. Finally it was leased by Howell to Messrs. W. S. Ditchett, W. L. Blake, and W. L. Blake, Jr., all of Bangor, under the name of Columbia Bangor Slate Company, an annual royalty being agreed on. This last leasehold dates from

[106] Sanders, R. H.: Op. cit., p. 91.

about 1890. Since then operations have been continuous, even including the period of the World War, with a production of about 20,000 squares of slate per year.

Recently the old bottom has been abandoned and a steam shovel used to remove the overburden east of the opening, a new working level thus being created. In August, 1924, a portion of this new level had been carried to a depth of about 55 feet, but stripping was being continued eastward. In November, 1926, this part was producing slate.

The quarry is equipped with two masts on the landing above the southeastern edge of the hole. Eight shanties were being supplied with roofing slate in August, 1924. There is no mill in operation, roofing slate being the sole product. The slate is quarried under the eye of an inspector who grades it before it is hauled out of the hole.

Geology of the New Bangor (western) part of the quarry.—The beds here show none of the abruptly turning structure characteristic of the southern limb of the syncline seen in the Columbia Bangor opening. Instead they preserve a regular northerly dip. The strike is generally N. 35° E., and the dip averages 16° N., but increases downward and northward. The beds seen at the surface lie immediately above the Gray bed and the latter itself appears 35 feet below the surface in the southwestern corner and passes into the northwestern wall of the quarry ten feet below the surface.

The cleavage generally strikes N. 45° E., and dips 17° S. Grain bears N. 45-50° W. and is vertical.

Three systems of joints are recognized, both in the upper surface and below, on the southwestern wall of the hole. These systems strike respectively (1) N.40-65°E., with dips of 40-75°N.; (2) N.5°W.-N.5°E., with planes having curved surfaces, so that the angle of dip varies from 20° to 50°E.; and (3) N.75°E.—N.80°W., with vertical planes. The last system largely consists of a series of dominant joints striking due east, between which are small discontinuous joints striking more nearly N.80°W. The second system appears to be independent of the others. Joints of the third dominate those of the first system and cut across them without being offset themselves. See Plate XXII, F.

History and development of the New Bangor part of the quarry.—This part of the quarry is really a part of the old Bangor Excelsior property. It was at one time known as the Howells quarry, but is now commonly spoken of loosely as the Bangor Excelsior, although that name should properly be applied to the next pit eastward. The present leasers are Messrs. Chas. R. Bray and John Parsons of East Bangor, Pa.* The property is a portion of the R. S. Brown Estate.

Operations were begun by Bray and Parsons in the summer of 1923, but were discontinued in 1924.

The equipment includes old masts on the dump to the south, a

* See footnote, page 155, as to present management.

boiler house, and an inclined track between this and the next opening to the west. The equipment apparently is to serve both the New Bangor and the Bangor Excelsior quarries.

In the past the quarry has yielded both millstock and roofing slate.

17. BANGOR EXCELSIOR QUARRY

Location and dimensions.—The northeastern edge of this quarry is parallel to the southwestern side of the New Bangor and is separated from it only by an inclined track. The opening is generally rectangular, with minor indentations, and measures roughly 450 to 550 feet. Water stands in the opening. The depth was probably 150 feet along the eastern side.

Geology.—The slate comes to the surface along all sides of the quarry, except the northwest, and apparently only the first ten feet are sufficiently weathered to constitute rubbish.

Probably the beds strike generally N.35°E., as in the New Bangor to the east, and dip about 15°N. The structure is a continuation along the strike of the lower limb of the Old Bangor syncline (see below). The quarry was opened in beds immediately above (i.e., north of) the Gray bed, the Middle big bed doubtless being encountered at a depth of about 35 feet below the surface.

Cleavage, as best it could be determined, strikes N.45°E. and dips 15°S. The grain trends N.50°W. and its plane is vertical.

The following joints were observed:

Joints in Bangor Excelsior quarry.

Number	Strike	Dip
2	N.40°E.	80°S.
3	N.35°E.	75°-90°N.
1	N.30°E.	70°S.
1	N.80°W.	vertical
1	N.80°E.	vertical
2	N.60°W.	vertical
1	N.65°W.	vertical
3	N.80°W.	vertical

It is thus seen that there are three systems, all dipping approximately vertically,—one striking N.30°-40°E., one striking N.80°W.-N.80°E., and one striking N.60-65°W. The first and second apparently correspond to the first and last systems listed as occurring in the New Bangor quarry, while the third has no counterpart in the New Bangor, unless indeed it represents only a slight variation in the strike of the N.80°E.-N.80°W. system.

History and development.—This quarry was already opened in 1874 to 1878 and was seen by R. H. Sanders, who described it under

the name of Bangor Valley quarry.[107] Of its recent history nothing was learned. It is not worked at present.

A power house and boiler stand at the northern corner of the hole. An inclined railway runs from the state highway up to the dump, having been operated by cable. Four cables with masts are still standing on the landing at the southeastern edge of the opening. An old mill, an accessory stockhouse, and various smaller buildings are on the dump, which lies mainly to the southeast of the opening.

Messrs. Bray and Parsons contemplated working the New Bangor only; very probably the two quarries, being closely adjacent and in the hands of the same owners, could be worked together, with common access to the equipment from both holes.

The main production from this quarry has been roofing slate, but it also yielded some millstock.

18. OLD BANGOR QUARRY

Location and dimensions—The quarry lies half a mile east of Bangor, on the south side of the state highway between Bangor and East Bangor. It is the third largest quarry in the district, measuring roughly 1200 by 550 feet in its greatest dimensions. The form in ground plan, however, is very irregular, suggesting two rectangles, an eastern and western one, measuring respectively 600 by 550 feet and 600 by 250 feet, placed end to end and with their longer dimensions forming the straight southeastern edge of the opening.

The old bottom of the quarry is water-filled, but the slate is exposed all along the southeastern side, attaining a thickness of not less than 100 feet along the northeastern and southeastern sides of the quarry. Recent work has been along the northeastern side where a shelf had been cut down 25 feet below the surface in September, 1923. In September, 1924, the working surface was an irregular platform about 60 feet below the surface on the same side.

A tremendous waste pile has been built up around the northwestern side of the quarry. Looking at it, one wonders whether all this slate would go back again into the hole. This dump rises 100 feet above the state road north of it, and measures 1200 by 600 feet. More waste material is south of the hole, where it has been built up as a foundation for landing and shanties. Plate XXIII A gives some conception of the size of this dump.

Geology.—The slate has an overburden of ten feet of glacial material along the northeastern edge of the hole.

The quarry exposes the Old Bangor syncline. This is a fold with an almost flat axial plane, the axis trending N. 42°E. The fold is shown in its true relations on the northeastern quarry wall, and here also it is seen that the upper limb dips more steeply than the lower,—

[107] Sanders, R. H.: Op. cit., p. 92.

PLATE XXIII

A. View of mill, dump, and southeast wall of Old Bangor quarry, from east corner of Bangor Union quarry.

B. East corner of Old Bangor quarry; looking N. 60° E. from middle of northwest side at the northward overturned Old Bangor syncline.

that, in short, the axial plane is not quite horizontal, but has instead a dip of 4°S.

As a part of the quarry is above, a part below the axis, the plane of which appears at the surface of the ground in the northern corner of the hole, the dip of the beds is north or south at different levels in the quarry; even near the axis of the fold, however, the dip is generally lower than 30°. The appearance of a very flat syncline, with limbs diverging only 30° or so, which is seen in the southeastern quarry wall, is, however, illusory and is caused by the small angle between the strike of the beds and the plane of this quarry wall; in this connection, reference should be made to Figures 24 B, and 25 A and C. The strike of the beds varies between N.30° and 62°E. For further illustration, see Figure 33.

The quarry has given its name, in the parlance of slate operators, to a series of beds generally spoken of as the Old Bangor "run." These include the sequence between the Thirteen big bed, which was quarried in the northern corner of the quarry along the axis of the fold, and the Nine Foot big bed, which is seen in the southeastern wall and outcrops in the eastern corner. The Gray bed comes to the surface at about the middle of the northeastern edge of the hole. A series of sandy beds exposed at the eastern corner (where, because the sequence is overturned, they lie above the Nine Foot big bed) was encountered in the deepest parts of the quarry.

The cleavage strike varies between the same bearings as were given for the bedding, but it generally trends more nearly due east than does the latter; the dips are nearly horizontal, rarely exceeding 4° in either direction. The grain plain strikes N.50°W. and is vertical.

The jointing was studied in detail only on the small ledge of the present working level. Here four systems were recognized, — one striking N.30°W., with dips of 75°N.; a second striking generally due east, with vertical dips; a third striking N.50°-67°E., with vertical dips; and a fourth striking N.20°-30°E., with dips of 60°-90°S. All joints observed clearly fell into one of these systems. Of these the N.30°W. joints are rare.

There are thus two systems of joints very similar to those in the Bangor Excelsior and New Bangor quarries, one striking northeast, the other due east (see Plate XXII, p. 153).

History and development.—The hill on which the Old Bangor masts now stand was once the property of Philip Labar. Robert M. Jones, who has been called the founder of Bangor, first discovered slate there and, with Labar, opened the quarry in 1863. Three years later Labar sold his interest in the quarry property to the Old Bangor Slate Company, the chief figure in which was Samuel Straub of Bangor. In 1880, the Lehigh Coal and Navigation Company bought

the majority interest in the property in order to obtain the freight on the slate by shipment over their new line between Bangor and Nazareth. This company leased the quarry to J. S. Moyer and Company in 1899 and the lease was thus held until 1914, when quarrying was discontinued. Prior, however, to the close of the lease, the Lehigh Coal and Navigation interests in the quarry were acquired by Robert S. Brown and in 1923 his interests were sold by his heirs to the Vendor Slate Company which resumed operations. The quarry was operated for a short period by that concern, but in 1924 it was sold to a new organization, the Amalgamated Slate Quarries Company of Easton, Pa., the main stockholders of which are Chester Snyder, George F. Coffin, James W. Williams, and Archibald M. Jones of Easton.

The quarry was formerly operated as two units, an eastern and a western one. Quarrying in the western portion was carried on from the northwestern side, where there are still standing, though now badly weatherbeaten, two masts, eight shanties, and a stock shed; in 1920 a large mill, also situated here, burned down.

The eastern part of the hole was worked from the hill toward the south which is now the site of all operations. Here are located eleven shanties (all operating), a mill which in 1923 was just being set up, and three masts with cables. The quarry has an omnipresent problem in the disposal of waste, which is now being thrown into the old hole or carried southward uphill.

The production in 1923 was confined to roofing slate, but it is expected that millstock will shortly be obtained.

A photograph of the dump, plant, and opening is shown in Plate XXIII.

19. NORTH BANGOR NO. 3 QUARRY

Location and dimensions.—This lies 200 feet north of the northeast corner of the North Bangor quarry, described below. It is 320 feet long in the direction N.57°E. and 100 feet wide in the direction N.50°W.; the opposite sides are parallel.

The hole has been filled along its southwestern side and is gradually being enlarged in the opposite direction. It has a depth of approximately 65 feet, but is being deepened as work proceeds; the bottom is the working level.

There is no water. The dump is largely to the southwest. Waste slate is also being carried to the dump of the large North Bangor quarry.

Geology.—An overburden of 5 feet of glacial till must be removed before slate is taken out.

The beds at the surface strike N.63°E. and dip 35°-40°S., but in the bottom they are seen to turn so as to dip 40°N. The structure is thus a northward overturned syncline, the axial plane of which dips

southward 8° and, to judge by the cleavage, strikes N. 80° E. Although this axis is thus considerably above the axis in the North Bangor quarry, it is clearly a part of the same structure, for quarrymen insist that between the two openings all beds dip southward at the surface.

In the North Bangor No. 3 quarry there are two big beds, the more northerly of which is called in this report the North Bangor No. 3 First big bed, while the lower and more southerly is the North Bangor No. 3 Second big bed; quarrymen do not use the terms "First" and "Second," having had little occasion to mention the two separately. The first bed is 7½ feet thick, the second 4½ feet thick; each has a prominent "hard roll" (sandy base). The two are separated by 15 feet of ribboned slate. Both big beds are exposed at the surface and can be seen in the northeast wall all the way down to the present working level. They are shown in the sketch, Figure 34, which represents

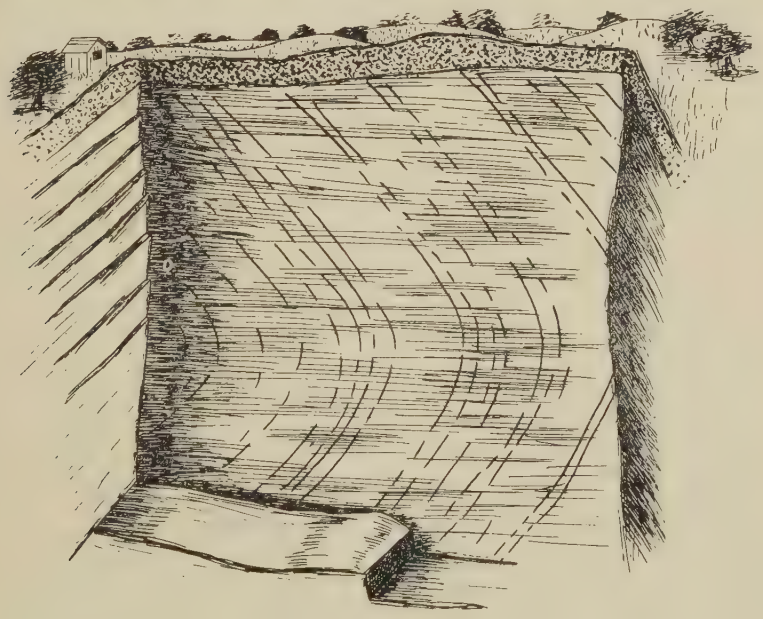


Figure 34. Old Bangor syncline, as seen in the northeast wall of the North Bangor No. 3 quarry; the dip is lightly increased through foreshortening.

a view of the northeastern wall from the surface on the opposite side; the angle of dip of the beds in this sketch is slightly exaggerated.

The cleavage strikes generally N.80°E. and dips 10°—20°S., with a tendency to decline upward. Grain trends N.48°W. and is vertical. Jointing is of two systems: (1) strike N.80°-85°E., dip vertical; (2) strike N.10°W., dip 40°NE. (see Plate XXII, p. 153).

History and development.—This quarry was open when visited by

Sanders[108] in 1874-78. The first operator was A. B. Thompson of Newark, N. J. Since then the history has been closely linked with that of the North Bangor quarry and with the North Bangor No. 2, which lay between the two other openings but is now hidden by waste. Operations in the North Bangor No. 3 have been discontinued several times. Thus Sanders already found it abandoned in 1874-78. Later is was worked for a time under the management of Mr. M. J. Spry of Bangor. Still later it was apparently closed again. At present it is being reopened, the eastern end being quarried, while the western end is used for disposal of waste.

The quarry is fitted with two masts. The mill will be described under the account of the North Bangor quarry.

Products obtained from this quarry include roofing slate, structural and sanitary material, electrical slate, and slate for blackboards.

20. NORTH BANGOR NO. 1 (NORTH BANGOR) QUARRY.

Location and dimensions.—The opening lies on the ridge between the main valley of Martins Creek and its east branch. From Bangor its dump is the first to be seen on this ridge. The hole is only about 2,000 feet north of the stream junction just referred to. It is 400 feet long by 250 feet wide, with its longer dimension in a N. 60°E. direction and a smaller rectangular arm of the hole projecting northwestward from its north corner. At its deepest the quarry is 330 feet below the surface of the ground, but it is said to have reached an even greater depth, since when the bottom has been largely filled with waste.

The work is on two levels, which are about 280 and 300 feet deep. These two working levels are parallel to and along the southwestern side of the hole.

The dump is northwest of the quarry and is being built outward toward the main valley of Martins Creek.

Geology.—An overburden of 20 feet of glacial clay and boulders is to be seen in the western corner of the hole. Some of the boulders are 3 feet in diameter. It is clear that this overburden diminishes northward (that is, up the hill) to about ten feet. Cribbing is used to intercept falling boulders loosened by frost action.

This quarry represents a portion of the same structure seen in the Old Bangor quarry and in the North Bangor No. 3 opening. The beds at the surface dip 25° S., but 65 feet below the surface they are vertical and 250 feet below it, on the uppermost working level, they dip 10°N., the average strike being N. 29°E. At the surface the strike is N.65°E. This fold has an axial plane striking about N.60°E. and dipping 9°S. It is well seen in the northeast side of the hole, a photo-

[108] Sanders R. H.: Op. cit., p. 92.

PLATE XXIV

A. Upper part of northeast wall of North Bangor quarry, as seen from middle of southwest side. The trace of the Old Bangor syncline is suggested. The big bed to the right (south) of A is the Mike Taylor big bed.

B. Northeast side of Northampton quarry at Bangor as viewed across the opening. Typical bedding slip fault. The crushed fault zone is at A. Closely spaced joints are seen to the right (south) of A.

graph of which is given in Plate XXIV, A. As shown in the section describing the North Bangor syncline, the axis here begins to turn northward—a feature better marked in the Old Bangor quarry, where the axial plane strikes N.42°E.

The beds exposed in this quarry are placed by the quarrymen in the North Bangor "run". They include two big beds, one of which is unnamed and which it is proposed to call the North Bangor big bed; this is about 7 feet thick. The other, the Mike Taylor big bed (see Plate XXIV, A), is about 8 feet thick. South of and 50 feet below this in actual thickness of beds lies a smaller big bed, with a heavy "hard roll", the two together being about 4 feet thick. This latter bed outcrops at the extreme eastern corner of the quarry dipping south, and appeared again in the deeper part of the old opening, which is now waste-filled, dipping north.

The cleavage strikes N.80°E. and dips generallly 9°S. Grain trends N.54°W. and is vertical.

The joints observed are of two systems; the strikes are N.32°E. and N.70°E.; joints of the former set dip 55-80° E., of the latter vertically. One joint strikes N.15°E., and dips 70°S. In general, the joints stop at the "sparry" ribbons that occur at the base of the Pinhead "run." This and higher ribbons are slickensided; it is thus clear that the movement along these ribbons in part relieved the pressure to which these joints are due. The joint diagram is shown on page 153.

History and development.—This quarry has had a long and interesting history. It was opened in 1862 by John Brown, who operated it until 1883, when a 50 year lease of this and the North Bangor No. 2 quarry (now filled with waste) was negotiated with Abraham Thompson of Newark, N. J., the main shareholder in the newly created North Bangor Slate Mining & Manufacturing Company. Thompson was in serious financial difficulties when, in 1887, he arranged a personal loan from Benjamin Atha and F. A. Wilkinson, who increased their investment until they were themselves heavily interested in the leased quarries. Atha and Wilkinson finally took over the management of the operations under the name of the North Bangor Slate Company. In 1913 the company was reorganized and the entire interest was sold to Albert Strunk, D. H. Keller, and Wm. H. Smith of Bangor, the present owners. Capital stock valued at $60,000 has been issued by the company. The ownership of the property is vested in the John Brown Estate.

The quarry is now worked with the aid of cables from four masts along the northwest side near the west corner. Two other masts are near the north corner on the same side, but are not now in use. A sketch map, not drawn to scale, is presented to show the arrangement of the mill and works (Figure 35).

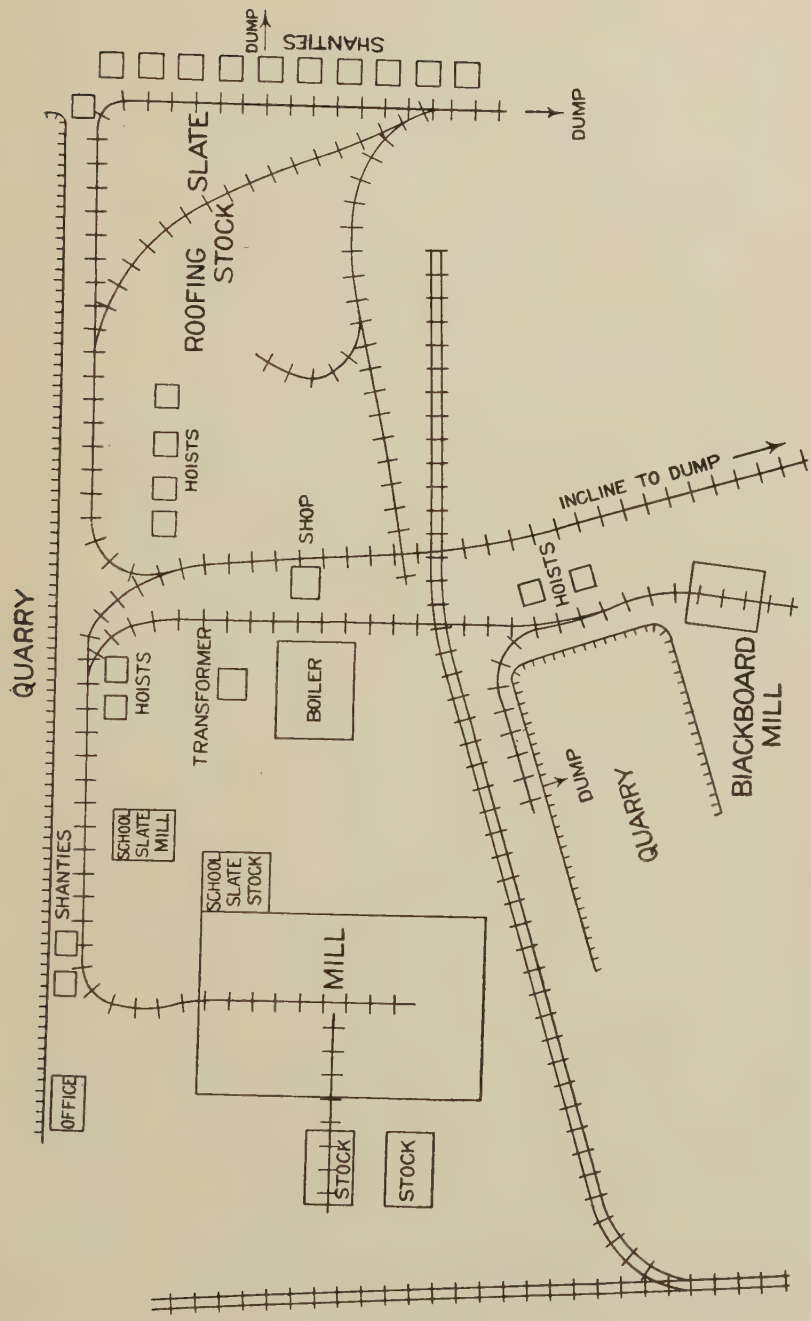


Figure 35. Sketch plan of mill, dumps, and quarries of the North Bangor Slate Company.

The mill is well equipped with six saws, four planers, two rubbing boards, a multiple-head buffer, a carborundum wheel used as a saw, and two whetstones. The planers on one side of the mill are arranged between the saws. In front of the mill two large buck saws are utilized to cut up the heaviest pieces. A boom and grapple handles the large slate blocks. The waste when from the North Bangor No. 3 quarry is partly thrown into the old hole to the east of the present workings, and partly over an incline to the north of the roofing slate stock pile. The waste from the shanties is dropped downhill to the west. These dump locations are shown on Figure 35.

Roofing slate is stored outdoors.

Of special interest here is the yield of school slate. This is made from thin beds of a color somewhat darker than that of most Bangor slate. The stone is trimmed to small sizes with a rapidly rotating saw, square in shape, with a large triangular tooth at each corner of the square. The standard sizes are 4 by 6 inches and 9 by 13 inches. For a description of the technology of the manufacture of school slate, see the section on school slate.

Another feature of interest at this quarry was the attempt by the manager, Wm. H. Smith, to train slaters. The number of older workmen, many of whom were taught in Wales, is gradually diminishing and no one is left to take their places. The effort was made, therefore, to attract boys during the vacation and to give them the necessary skill that they might, at the age of eighteen, become splitters and trimmers. The experiment has been less fruitful than expected, but is also being undertaken in some of the Pen Argyl quarries and will, it is hoped, prove helpful ultimately in overcoming difficulties created by the diversion of labor into other industries where a shorter apprenticeship is required.[109]

Besides school slate all types of slate products—roofing slate, sanitary and structural material, blackboards, and electrical slate—are yielded by this quarry.

21. BANGOR UNION QUARRY.

Location and dimensions.—This opening is a quarter of a mile north and 500 feet east of the post office at Bangor. It is roughly rectangular and 550 by 400 feet in size, with its longer dimension northeast. Its greatest depth now is 230 feet, but it has been largely filled with waste. Stripping is beginning to develop a smaller hole, 25 feet deep (1923), continuous with and along the southwestern edge of the larger opening. The property line between this and the North Bangor quarry lies generally along the sharp wall which separates the two main openings.

[109] For further details in regard to this interesting subject, see Sanger, A. G.: "Back to School" in the Roofing Slate Industry, Rock Products, Vol. XXVI, p. 30, 1923.

The principal dump of the Bangor Union is built toward the northeast and north of the hole; the slate waste must be hauled thither by rail. Some waste is also thrown into the large opening of the Bangor Union, which is now no longer worked.

Geology.—Glacial material 20 feet or less thick is seen above the slate. This quarry is in beds lying stratigraphically just below the strata exposed in the North Bangor quarry and slightly farther east along the strike, so that the beds and structure in the Bangor Union may be said to begin where those of the North Bangor leave off. The strata at the surface dip 20°S., with strike averaging N.70°E.; 100 feet below the surface they strike N.34°E., dipping 13° N. in the south corner of the quarry. The syncline, resembling in appearance that of the North Bangor quarry, is cut by the somewhat curved quarry wall in the northwest edge of the opening. The strike of the axis is about N.65°E. This "tight" fold with some slight undulations in the axial plane, produces, when cut by the southwest quarry wall, the appearance of a wedge with a very sharply pointed apex.

The slate in the southwest wall of the opening includes three big beds, which, in the order named are, from top to bottom, the Bangor Union big bed, the Black Ribbon big bed (also called the Balmoral big bed) and the Thirteen big bed. The same order, obviously, holds from north to south at the surface.

The cleavage strike varies greatly, but is generally N.60°W., with a southward dip of less than 10°. Grain trends N.50°W., and is vertical. Beneath the axial plane of the fold, joints striking N.50-55°E. are seen dipping vertically. Near the axis joints striking N.60-70°E., are developed, apparently of the same system, also vertical and generally tangent to the beds. These are complementary with a set of N.65-90°W. joints, which branch off from the northeast striking joints. A third set strikes N.10-35°W., with vertical dips; these are small, and apparently tensional products at right angles to the line of compression expressed by the N.60°E. joints. There are thus three systems, all vertical and striking respectively: (1) N.50-70°E., (2) N.65-90°W., (3) N.10-35°W. This yields a pattern closely resembling that of the Old Bangor quarry (see Plate XXII, p. 153).

History and development.—This quarry was opened about 1870; from then until 1890 it was operated as the Elmira quarry. It was then taken over by the Auld & Conger Company of Cleveland, Ohio. Its present manager is Mr. O. Seager of Bangor, who operates the quarry for the company.

Five masts serve the quarry, the cables being anchored on the southwestern side. When the quarry was visited in 1923 four shanties were in operation, although a short idleness, due to a partial cave-in, had reduced the work. As many as ten shanties were working be-

fore the cave-in, it is said. The new hole, on the southwestern side, was just being opened in 1923. This now yields all the slate produced on the property.

The principal yield is roofing slate, but much milled slate is also produced. A small but well-equipped mill is in operation, with two rip saws, two buzz saws, three planers, a rubbing bed, and a drill press. One of the ripsaws is mounted in series with the buzz saw and planer on one side of the factory. A hand operated crane, mounted on an overhead track, connects this saw with the planer on the opposite side of the mill; the saw can thus be used for recutting irregularly planed blocks. Another crane is mounted on a carriage supported by two overhead tracks, one along each side of the mill. This permits movement of large blocks down the length of the building. These were the only cranes for moving slate in the factory seen in the Bangor district in 1923.

22. BANGOR WASHINGTON QUARRY.

Location and dimensions.—The opening is 1200 feet northeast of the Bangor post office, on the east side of the state highway. It measures 225 by 400 feet, the longer dimension being in the northwest direction. These measurements, however, are based on observations in the early summer of 1923. In 1924 a considerable area to the northeast of the old hole had been stripped of its overburden and progress was made toward opening a new hole in this stripped area.

The old quarry was filled with water except for a short time in 1924. At present the slate shows for 15 feet or so above water level, although the opening must be quite deep below this, to judge by the dump.

The waste was formerly hauled uphill to the southeast by cable car. Economy of effort might be achieved by dropping it into the old opening.

Geology.—The overburden is heavy, consisting of sand, boulders, and clay, originally glaciated material laid down presumably by a stream.

The beds exposed in the old pit were mainly those on either side of the Gray bed, which, it is said, was to be seen near the middle of the northeastern side of the hole. The beds here are on the lower (i.e., originally the north) limb of the recumbent syncline described in the Old Bangor quarry. The upper (or south) limb has been worn away, leaving the beds practically vertical along the southeastern wall of the quarry, but with a rapidly declining dip to the north as the northwest wall is approached. The southeast wall of the quarry is thus on the axis of the fold at the surface. In general, the strike of the beds is N.50-60°E. Cleavage planes were not accessible, but appeared to dip gently south with the same strike.

Prominent joints seen in the southeast corner strike N.68°E. and dip 45°S.

History and development.—The quarry is operated by the Bangor Washington Slate Company. The land is a part of the Albert Strunk, J. S. Strunk, and Margaretta L. Moyer Estates. Slate was first quarried here by Philip Labar in 1868. The property was then sold to Fulmer and Wagner, who worked the quarry for a short time. After ten years of idleness Albert Strunk, J. S. Strunk, and Joseph K. Husband leased the quarry under the name of Strunk Brothers and Husband, continuing to make slate until 1905. At this time J. S. Moyer & Company, operators of the Old Bangor quarry bought the quarry. In 1907, the Bangor Washington Slate Company was formed with Albert Strunk, J. S. Strunk and J. S. Moyer as the principal stockholders. Operations are now in the hands of this company.

The quarry is now being worked. Four shanties were busy immediately after the strike in 1924. The slate is hauled up the incline or taken by cable directly to the landing on the southeastern side of the opening. Two cables are in place.

For many years roofing slate and school slate were made, but as the school slate industry declined this phase of production was discontinued. Since 1895 only roofing slate has been produced.

23. NORTHAMPTON QUARRY.

Location and dimensions.—This quarry lies apart from the other openings of the Bangor Group. It is situated about one and one-half miles north of the Bangor post office and less than a mile from the little town of Roseto. It is connected by rail with the Lehigh and New England Railroad to the west.

The opening, about 250 feet square, is roughly in the form of a parallelogram, with two of the sides bearing northwestward.

It is worked in two levels and when studied was being stripped in the northeast corner to form a third level as well. The lowest working level has a depth of 230 feet below the surface in the sump, while at the highest portion of the upper level the excavation is 60 feet deep and occupies the northwestern part of the hole.

The dump is built up mainly to the south along the margins of the opening.

Geology.—The slate in the northern corner is covered with an overburden of twelve feet of glacial clay and boulders. The latter are partly well faceted; even some striated boulders were seen. In the western corner a similar overburden shows, but here is thinner (eight feet) and more gravelly.

In general this quarry shows bedding standing almost vertical at the surface, but decreasing in dip with increased depth; this decrease is accompanied by a reversal, for at the surface the beds, if not upright, dip northward, while below they dip southward. The average of six strike observations at various levels is N.58°E; as this is also

approximately the mean on each separate level, it may be assumed that there is no torsion in azimuth of the axis of the major fold shown in this quarry.

The fold thus seen is, so far as exposed in the quarry wall, very "open," with but little thickening along the axis.

There is much dispute in regard to the correlation of the beds exposed. Among the quarrymen generally it is believed that the slate is of the Diamond "run" in the Pen Argyl beds. This belief rests on two observations: first, the slate is "soft" and easily shattered, resembling in this respect the beds worked in the Diamond "run" at Pen Argyl; second, the observer, standing on the dump between the old Diamond and the United States quarries at Pen Argyl and sighting eastward in line with the compass direction of the outcrop of the Diamond "run", is looking in the general direction of the Northampton quarry. Against these two lines of evidence, other facts may be cited. First, it is apparently true that all slate so far encountered lying north of (that is, above) the beds opened in the Diamond quarry at Pen Argyl is "softer" than that lower down in the sequence; thus, the slate in the Fidelity and West Bangor quarries is of this character. Second, there is no actual correlation, bed for bed, between the sequence in the Diamond "run" and that in the Northampton quarry. Accurate measurements of the sequence in the Doney, New Diamond, and Parsons quarries, compared with those in the Northampton, do not clearly established any correlation. Third, there is good evidence, as will be seen from what is said below, in the description of the Pen Argyl quarries, that the beds take a marked northward turn as they approach Roseto from Pen Argyl; if anything, therefore, sighting eastward along the strike of the beds at Pen Argyl is almost certain to carry one into lower, more southerly beds.

Mr. Spry of Bangor, on the other hand, assigned the beds of the Northampton quarry to the Acme "run" as exposed in the Acme quarry at Alpha, west of Pen Argyl. Certainly as much can be said in defense of this position as of the one more commonly held. The measurements, in the opinion of the writer, favor this correlation if any. The big bed exposed near the south edge of the lowest working level in the Northampton quarry would correspond to the second big bed from the south edge of the Acme Quarry's top piece. If this correlation is correct, the Northampton property should contain the Albion beds and a trench cut sixty feet at right angles to the strike from the northwest edge of the present hole should just strike the Hard Front big bed.

The data so far obtained do not finally establish the correlation between the beds in this and other quarries.

Three big beds are worked in this quarry. On the upper level a bed 82 inches thick, yielding a length of 86 inches along the cleavage and

with a thickness of 33 inches of "hard roll", is profitably worked. Farther south and on the lower level are other big beds, the northern having a thickness of 64 inches, with a 9 inch "hard roll", the second with a 97-inch thickness and a "hard roll" of 15 inches. Of the three big beds enumerated, the northern (upper) corresponds most nearly to the Red bed of the Diamond "run", if it is to be at all correlated with a bed of the Pen Argyl group. It bears a conspicuous "hard roll," in which the cross-bedding has a marked westward dip.

The cleavage strikes N.67-75°E. in all observations; its dip varies from 13-18°S. The grain trends N.50°W., and is vertical or nearly so.

The jointing in this quarry follows two general systems, one trending N.60°E., with dips of 45-50° N., the other N.60°W., with southward dips of 45°. The northeast joints are the more conspicuous. One of the northwest joints bears lenticular depressions similar to those of the Bangor Central and other quarries, but in this instance they are not pyrite-filled. A minor system of closely spaced, irregular, roughly northward trending joints was seen in the upper level, merging in many instances with the grain planes so that grain and joints are indistinguishable. A few small calcite-filled, N.50°E. joints with vertical planes are seen here also.

This quarry shows several unusual features. There is a thick calcareous and chloritic stratum near the middle of the northeast wall of the quarry on the lowest level. This consists in detail of two calcareous beds, each about an inch wide, heavily fractured and separated by a chloritic layer which reaches a maximum thickness of two inches. The chloritic band narrows here and there, whereupon the two calcareous beds come together, separating again as the chlorite widens. It is as though there had been deposited two beds of limey sediment with a layer of calcareous mud of varying thickness. This was all folded while under sufficient overburden to be plastic; at that time the calcareous beds were broken and faulted and the muddy sediment squeezed to thicken here and thin there, expanding in the places where the pressure tending to bring the calcite beds together was less than elsewhere. The development of cleavage, the fracturing of the calcite and the pouring of the calcareous muds into the "swells" between the calcareous beds,—these were all effects of one and the same deformation, as may be seen at a glance in Plate XXV, B.

In the northeast wall there is a bedding slip fault, similar to that described in the New Peerless (Bangor Vein) quarry. In this instance joints are again developed along the fault and the cleavage has been severely distorted, making quarrying immediately along the fault plane not only profitless but dangerous. A discussion of this type of fault has already been given (see p. 66). Although the feature

mentioned adds expense to the operations, the slate thirty feet north and south of the fault plane seems wholly acceptable as structural material. The fault is illustrated in Plate XXIV, B.

History and development.—The Northampton quarry was opened by Solomon Flory in about 1885, in partnership with J. Featherman and several citizens of Wilkes-Barre. In 1896 the interest passed into the hands of the Northampton Slate Company, but this organization failed. In 1898 the present owners, under the name of the New Northampton Slate Company, took over operations. The New Northampton Slate Company leased the property to the American Slate Company for ten years, the lease expiring in 1909, when it was taken up by the Hamman Slate Company. The latter failed in 1923; in the same year William Smith, representing the North Bangor Slate Company, leased the property, and it is this organization which now operates the quarry.

Four cables serve the hole. There are the usual power house, machine shop, and office. A well equipped mill is situated to the south of the opening. This is furnished with machinery arranged so that a complete series, consisting of buck-saw, planer, rip-saw, and planer, is present on each side of the factory, the buck-saws being nearest the door. Pivoted vertical masts with booms permit the swinging of large blocks from one machine to the next in the series. Two rubbing beds, an accessory rip-saw for trimming, a carborundum wheel, and a movable single-headed buffer complete the equipment. An accessory, exceptionally large boom is mounted in front of the mill, and near it is a large buck-saw on which the heavier blocks are cut in two to facilitate handling. Blackboard and mill slate stock houses are in the rear of the mill.

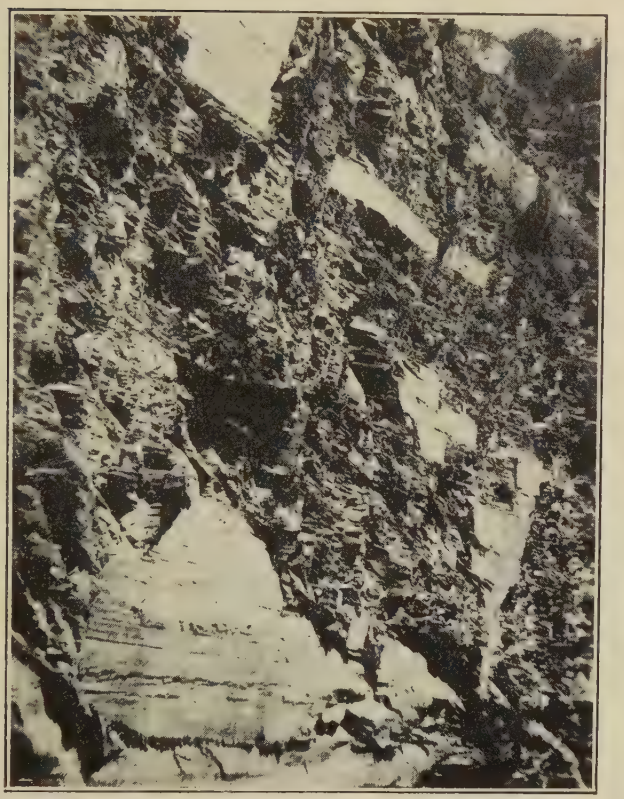
The products are blackboards, millstock, and roofing slate. All three of the big beds are used for blackboards. Electrical slate comes largely from the big beds and from several small beds close to the northernmost of these.

24. SHAFT ON BLAKE'S PROPERTY.

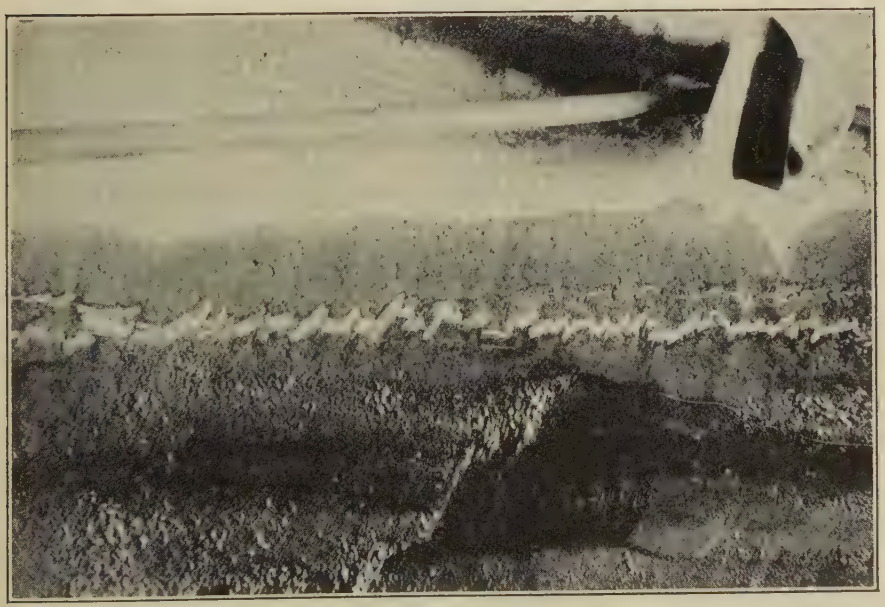
Location.—This opening is on the Blake farm, about half a mile west of the Bangor post office and 400 feet south of the Bangor-Pen Argyl highway.

This is a small vertical shaft said to have been sunk to a depth of about 60 feet. Several smaller shafts were dug in this lot, but only one struck slate.

PLATE XXV



A. Northeast wall of the North Bangor quarry, working level. To show contrast between blasted (rough) and channelled (smooth) surfaces.



B. Minutely fractured calcareous bed on northeast wall, lowest level of the Northampton quarry.

Geology.—As the walls of this shaft had caved in, the slate could not be examined. The following account is pieced together from information obtained from several sources.

After passing through a great thickness of glacial sand and boulders (evidently terminal moraine material), slate was struck. The beds found are said to have been about the bottom of the Bangor "run"; it is said that the 9-Foot big bed could be identified. The cleavage dipped south; blocks of the slate found on the surface were properly oriented (assuming a grain strike of N.40°W.) and the bedding strike was thus determined to be N.70°E.; the exact inclination of the bedding could not be determined, but it is gently northward.

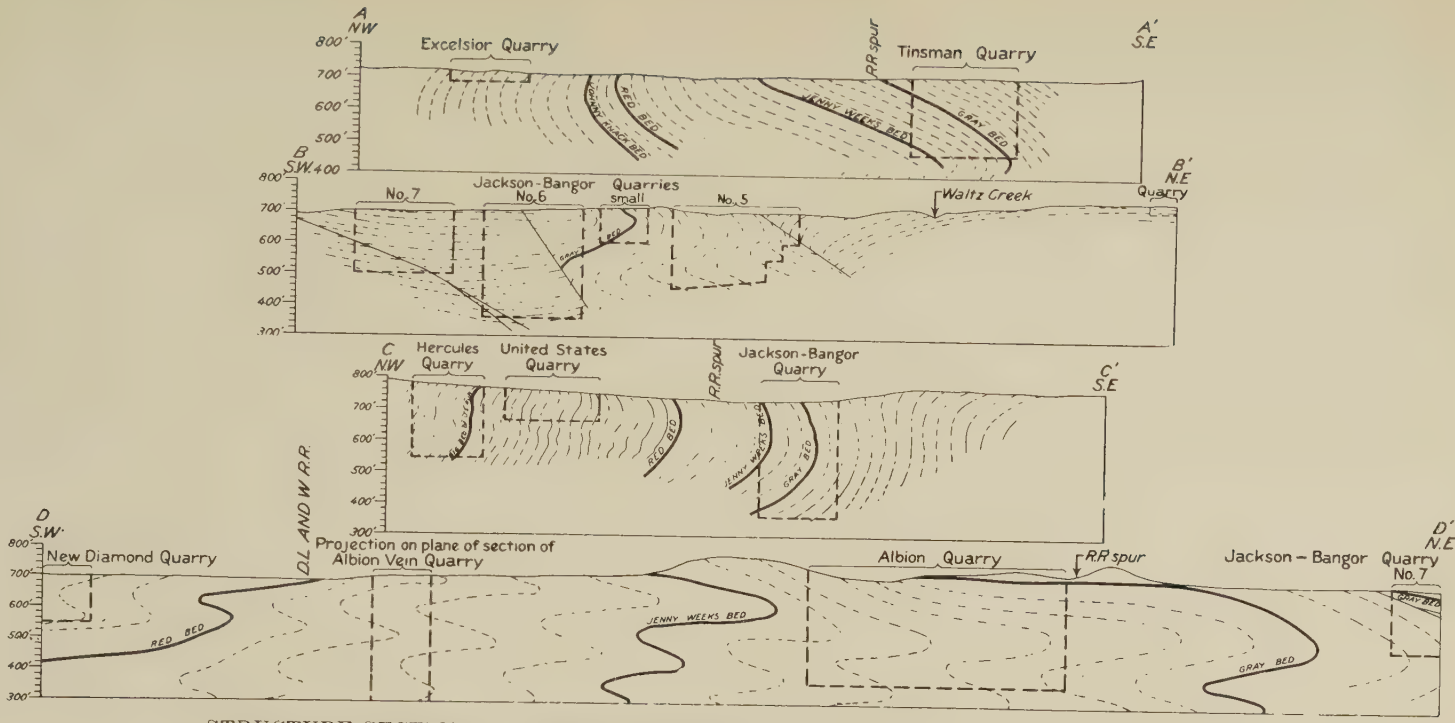
Wind Gap—Pen Argyl Group

SUMMARY.

The quarries of the Wind Gap and Pen Argyl group center around and secure their supplies from these two towns. Pen Argyl is, in fact, primarily built on the slate industry, although the shops of the Lehigh and New England Railroad at Alpha absorb some labor from the town in normal times. A few of the quarries that lie nearer the outskirts of this natural grouping might normally trade in Bangor or Factoryville.

Like the quarries of the Bangor group, the operations at Wind Gap and Pen Argyl are in the soft belt. The upper portion of the upper member of the Martinsburg is called the Pen Argyl beds, from the fact that it is exposed in the quarries in this group. The minor subdivisions or "runs" are named after the older quarries at Pen Argyl, hence such names as Acme, Phoenix, Albion, Diamond, and United States "runs". This strip of Pen Argyl beds, including the runs mentioned and others, is readily identified at the Albion Bangor quarry and can be traced eastward, in a nearly straight line, with only slight flexures, as far as the Jackson Bangor No. 5 (Valley) quarry. Farther east the correlations are either uncertain or the statements of old quarrymen must be accepted, in the absence of accessible quarries in which the beds can be measured. Thus the correlation of the beds in the Northampton, New York, and Hoboken quarries, of the Bangor group of quarries, is in doubt.

Were the correlations merely a matter of sighting eastward or westward along the strike of the "ribbons" or beds, it would not be difficult to establish the exact stratigraphic position of a quarry site in advance of operations. But in the quarries of this group the effect of topographic elevation on the outcrop of a bed is again a complicating factor, for the strata are thrown into folds which, though open, nevertheless attain dips as low as 30° on the limbs (see Plate XXVI).



STRUCTURE SECTIONS IN WIND GAP-PEN ARGYL DISTRICT; Scale 1 inch = 600 feet.

AA′ Section N. 20°W. through Tinsman quarry.

BB′ Section N. 70°E. through Jackson Bangor No. 5, 6, and 7 quarries.

CC′ Section N. 25°W. through west edge of Jackson Bangor No. 6 and Hercules quarry.

DD′ Section N. 65°E. through New Diamond and Jackson Bangor No. 7 quarries.

From the Albion Bangor eastward to the Tinsman quarry it is apparent that the surface structure on which the greater part of the openings are located is the north limb of an overturned anticline the axial plane of which dips south. From the Phoenix to the Acme and Alpha quarries the strata exposed at the surface dip north on the south limb of a syncline. In the Doney, Diamond, Albion Vein, Albion, and Jackson Bangor No. 7, 6, and 5 pits the strata dip southward at the surface. In some quarries, such as the Albion Vein, several small folds are encountered as successive depths are attained. It is highly probable that these structures all pitch westward.

The cleavage commonly dips south, but rarely (as in the Albion quarry) inclines northward. It is generally fairly regular, although in a few places, near surfaces along which movement has taken place, cleavage planes are so badly warped as to preclude the use of the slate affected.

There is faulting of various kinds in these openings. Bedding slip faults, already mentioned as occurring in such quarries of the Bangor group as the New Peerless quarry, are found at Pen Argyl; further, an unusual type of fault plane, striking northwest, dipping northeast, and along which displacements of as much as 125 feet in the direction of movement are recorded, is not uncommon.

For the most part joints in these quarries strike approximately parallel with the cleavage, but no further generalizations can be made. The close resemblance between joint systems in quarries that lie near each other is noteworthy.

The products of the quarries of this group are varied, and include all the articles commonly made from slate. Quarries opened in beds above the Pennsylvania "run" or below the Albion "run" generally find the production of structural, electrical, and blackboard slate more profitable, and make roofing slate in smaller quantities only, if at all.

At the time of these studies seventeen quarries were operating in this group. Some are very large, others of only moderate size. The district includes the Parsons opening, said to be the deepest slate quarry in the United States.

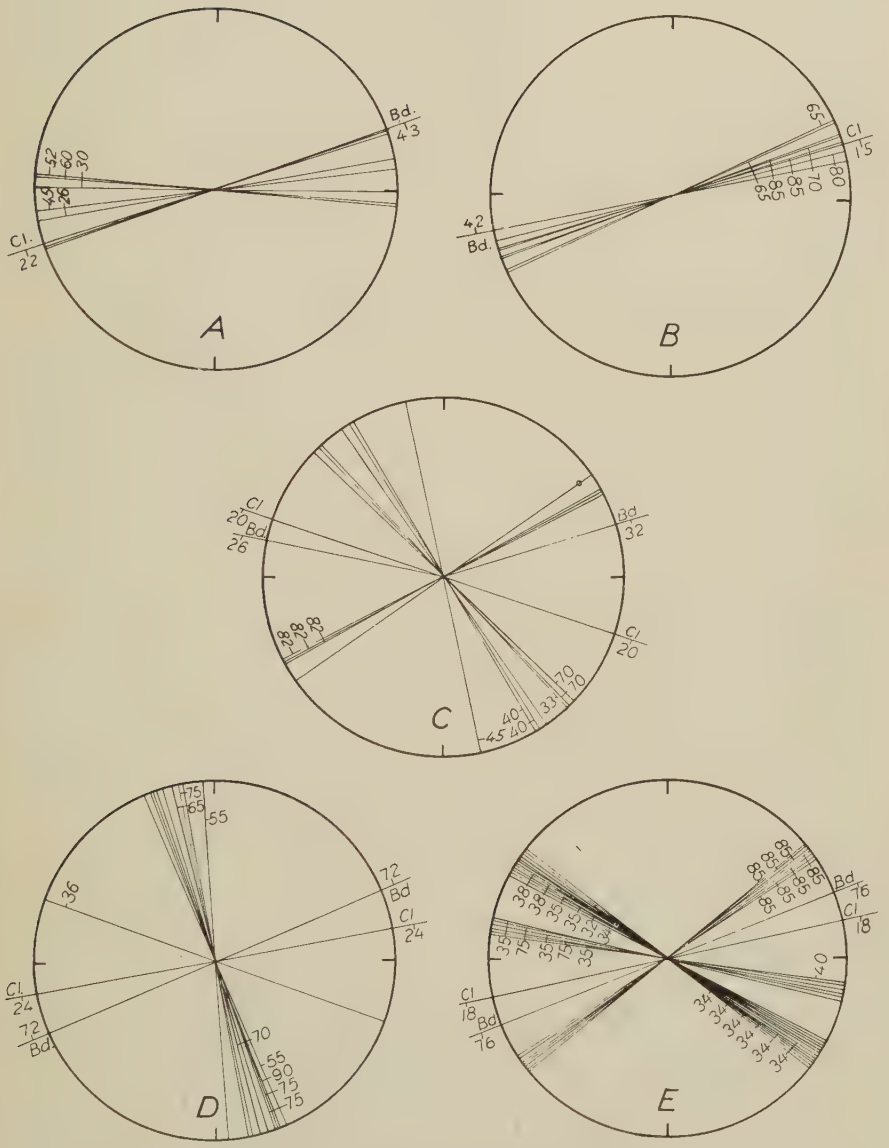
1. NUNGESSER QUARRY.

Location and dimensions.—This opening is on what is known as the old Nungesser property about two miles S. 60° W. from the post-office at Wind Gap and about a quarter of a mile north of the road from the Jackson school to Horn Springs. It lies well back from the road, hidden from view in a field.

The opening measures 50 by 70 feet and has a depth of 20 feet to water level at its south end.

Geology.—Beneath a very shallow overburden of decayed slate and

PLATE XXVII



STRIKES OF JOINTS IN QUARRIES NEAR WIND GAP AND ALPHA

A. Albion Bangor. B. Phoenix. C. Tinsman. D. Acme. E. Doney.

clay soil, two big beds and several smaller ones are seen. The beds are conspicuously sandy. The strata strike N.53°E. and dip 9°S. at the southern end of the quarry, but the dip steepens to 38° at the north. The cleavage strikes N.53°E. and dips more steeply than the bedding, so that a southward overturn is actually suggested.

History and development.—This quarry was opened about 30 years ago by Mr. Kinney of Wind Gap. The property was leased to an operator from Tobyhanna and the lease was then sold to a farmer. No slate has been removed in the last twenty years. Millstock and roofing material were the products.

2. ALBION BANGOR QUARRY.

Location and dimensions.—This quarry is the farthest west of those operating in the Pen Argyl region. It is half a mile west of Rismiller station on the now abandoned Lehigh and New England spur west of Wind Gap. In shape it is a rhomboid with a small accessory opening along its western side. The main hole measures 300 by 200 feet, the longer dimension extending northeastward. At the southwest corner there is a low section of the quarry forming the bottom "piece." This level is about 180 feet below the surface of the ground. To the east and south is a well-nigh continuous higher level, from 25 to 40 feet above the bottom.

Geology.—There is a strikingly heavy overburden of glacial material above the slate, reaching a thickness of 35 feet; just below the surface this consists of unassorted boulders, some of which are five feet in diameter. They are mixed with clay and faceted. The lower 25 feet are finer material, which was not closely examined because inaccessible but bore faint marks suggestive of stratification.

The beds in the northern corner of the opening strike N.70°E. and dip 53°S. at the surface, but in the southeastern part the dip steepens to 80°S. at a depth of 30 feet below the surface. It follows that an axis is being approached southward. The dip of the beds should thus decline as they are traced downward from the surface along the southern wall of the quarry. In the bottom of the present working levels the strike of the beds is N. 70°E. and the dip is approximately 43°S.

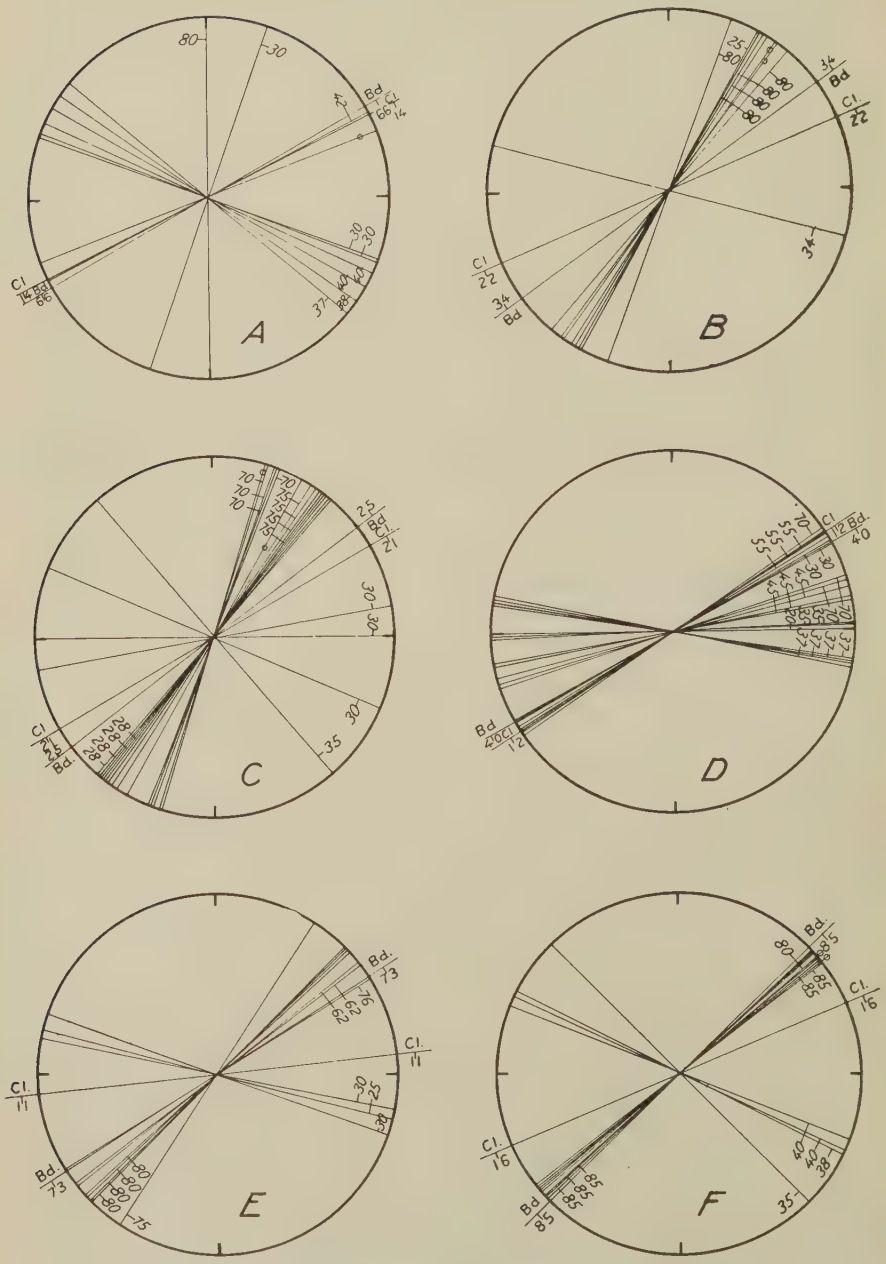
This quarry apparently exposes beds north of (i.e., above) beds of the New Diamond and Parsons quarries. A thick bed, probably the equivalent of the Johnny Knack big bed of the Diamond "run" (see measurements made in Parsons quarry), crops at the surface about ten feet north of the southwest corner. The calcareous ribbon that is exposed along the northern side of the Parsons quarry, in the Albion Bangor quarry comes to the surface about 45 feet north of the southwestern corner. In the Albion Bangor, on the combined working levels, about 115 feet in actual thickness of beds are exposed; here

PLATE XXVIII

A. Folding and bedding-slip plane in Albion quarry, as seen from the middle of the southwest side. The bedding slip plane is at the northeast (left) edge.

B. Northeast wall and 380-foot level of the Parsons quarry. Regular joints are seen on the northwest (left) wall, which is formed by a "loose ribbon." Photograph by Bliss, Easton, Pa.

PLATE XXIX



STRIKES OF JOINTS IN QUARRIES NEAR PEN ARGYL

A. New Diamond. B. Albion, Keenan half. C. Albion, Stephens-Jackson half, bottom. D. Albion, Stephen-Jackson half, upper part. E. Parsons, top piece. F. Albion Vein.

are mainly strata not shown in other operating quarries. There are included in this sequence several big beds, of which the most conspicuous is on the lowest "piece"; this measures five feet in thickness with an additional four-inch sandy layer at the southern (lower) end.

The cleavage strikes about N.73°E., and dips 18-25°S., a rather high angle. Grain trends N.47°W. and is generally vertical.

The joints in this quarry have a conspicuous easterly direction and either parallel the strike or form small angles with it, dipping gently northward. The diagram (Plate XXVII, A) clearly shows their general parallelism. These joints, together with the cleavage openings, serve as courses for water, although some water also enters through the loose ribbons,—openings formed along calcareous beds.

History and development.—This quarry, also known as the Blue Mountain quarry, is now owned by the Albion Bangor Slate Company. It was opened in 1895 by Tiney Allen and was operated until 1905 by the Blue Mountain Slate Company. It was then purchased by the Albion Bangor Slate Company, by which it was worked until 1924. In that year both main stockholders died, and, as operations had not been profitable, a receivership was appointed. The property was offered for sale in 1924, since when its history has not been followed.

The quarry is equipped with three masts, well mounted in concrete. A small mill is on the dump south of the quarry. This building houses two of each of the following,—buck-saw, rip-saw, and rubbing bed. There are three planers, a Pollard carborundum wheel for cutting and bevelling, and a small emery wheel for sharpening saws and planer knives. The usual practice of placing a heavy buck-saw and a large boom with block and tackle outside the door of the building is followed. The machinery is driven by two parallel shafts of which one is linked directly to the power, while the other is connected to the first by a belt.

The yield in the past has included electrical, roofing, and structural slate, as well as blackboards. In recent years, however, structural material alone has been produced.

3. ARVON QUARRY.

Location and dimensions.—This opening is separated from the Albion-Bangor quarry just described by a strip of ground only 30 feet wide. The opening is about 200 feet wide and 400 feet long, the greater dimension extending northwestward parallel to the grain of the slate. The deepest point of the hole is 130 feet below the surface at the base of the masts. All walls except that to the northwest are sheer, but the latter has a gentle southward slope so that the bottom of the quarry has an area only about half the size of the opening at the surface. A portion of the original bottom of the quarry is also filled by an old slide of rock which fell from the northern wall.

A dump is built up at the surface along the southern edge of the opening.

Geology.—An overburden of glacial material similar to that seen at the Albion Bangor covers the slate here. It thins southward noticeably along the eastern side of the quarry. In the southeastern corner the boulders become less conspicuous and the glacial cover seems to be very fine clayey material, almost loess-like in appearance.

The axis predicted in the southerly part of the Albion Bangor opening actually becomes visible in the southwestern corner of the Arvon quarry. Here the beds dip 60°N., (estimated) 25 feet below the surface and dip vertically an equal distance deeper. The axis of the fold thus defined strikes northeastward and dips south 25°; along the northern edge of the quarry, however, the beds strike N.74°E. and dip 55°S. As the observer descends vertically he sees a progressively diminishing dip on this side of the quarry, as might be anticipated from the structure described.

The beds exposed are those described in the Albion Bangor quarry; this is to be expected, as the Arvon lies along the strike from the other opening. However, a portion of the workings of the Arvon must be in the same beds as the top "piece" of Parsons quarry if the correlation advanced above between the beds of the Albion Bangor and Parsons quarry be correct. The present opening of the Arvon thus exposes a greater thickness than does the Albion Bangor quarry. The beds thicken notably as they approach the surface.

Cleavage is fairly uniform. It strikes N.73°E., and dips 24°S. (average of four observations). Grain trends N.38°W., and dips 75-90°W.

The joints observed fall into two systems. Of these one is a set of flat joints, having average strike of N.70°E., and dipping 6-10°S. These are commonly spoken of as "floors" by the quarrymen and are remarkable in being nearly parallel. A second series strikes roughly east, and dips 45°N., but is irregular, yielding curved, rather than straight surfaces.

A feature called "catspaws" by the quarrymen was observed in this quarry. This consists of surfaces which are very gently curved, so gently indeed that they swell but little beyond the cleavage planes on which they are developed. They give the appearance of great blisters, locally as much as nine inches in diameter, on the fairly smooth cleavage planes (see also p. 75).

History and development.—This quarry was opened in 1911 by a company consisting of Messrs. Ely, Seipel, and Myers, residents of Wind Gap. Later, incorporation as the Arvon Slate Company was effected. When visited, operations were under the management of Mr. D. B. Heller of Wind Gap.

The equipment consists of a saw mill, with two heavy saws, a rip-saw, three planers, two rubbing beds, a buffer of Vermont type, and a carborundum wheel that is used for trimming. A large boom and tackle handle the heavier blocks outside the mill; within the mill the slate is transported on a track.

The products are roofing slate, blackboards, structural material and a little electrical slate. There are generally too many knots in the slate to make the production of much electrical material practical.

4. EXCELSIOR QUARRY.

Location and dimensions.—This opening is half a mile west of the Wind Gap post office and some distance from a principal highway. A spur running from the Lehigh & New England Railroad connects it with the Saylorsburg Branch of that line.

The quarry is almost square, measuring roughly 200 feet in each dimension. In the summer of 1923 it was filled with water to within ten feet of the surface. The depth below this is not known.

Geology.—The slate is covered with two feet of clay and boulders. Some of the boulders are rounded, but the rounding does not approach perfection. Boulders of red sandstone (High Falls or Catskill), buff sandstone, conglomerate, and quartzite—the latter mainly from the Shawangunk—are common in the surface material. Downward the overburden passes gradually into clay bearing slate flakes, and this in turn gives place to weathered but solid slate. The cleavage planes in the latter tend noticeably to stand more nearly vertical as they approach the surface, as compared with their attitude lower down,—a circumstance due to surface creep.

The beds appear to strike in a direction approximately N.45-65°E., though these bearings are estimates only. The dip averages 57°N. The structure thus appears to represent a continuation of that seen in the Arvon quarry in the east wall. It seems certain that with depth the beds would approach a vertical dip, and then gradually reverse until they inclined southward.

The most reasonable interpretation of the structure between this opening and the Tinsman quarry, in which the Gray bed of the Albion "run" is seen, leads to the conclusion that the operations in the Excelsior were yielding slate from the Diamond "run." This interpretation is in accord with the commonly expressed views of quarrymen.

The cleavage strikes N.62°E. and dips 40°S. where accessible to measurement. The grain trends N. 45° W., and stands vertical.

History and development.—Mr. John F. Hess of Easton, Pa., who is the present owner of the property, states that this quarry was operated between the years of 1900 and 1920 by Thomas Masters, Jr. Upon his death work ceased, and the quarry reverted to the heirs of the

estate. The property consists of 7.5 acres of land. Three masts are placed on the landing.

On the dump south of the quarry there are a boiler house, one shanty, and a factory, which was not visited, but is said to be well equipped.

The products included some roofing slate, as well as blackboard and structural material.

5. PELICAN QUARRY.

Location and dimensions.—This quarry is about half a mile east of Rismiller, on the south side of the main highway between Rismiller and Wind Gap. It measures roughly 150 by 300 feet and is 60 feet deep to water level but is probably much deeper. The large dump is on the south.

Geology.—The overburden is not over five feet and consists partly of slate chips, partly of faceted or rounded glacial boulders, set in a clayey matrix; no stratification is seen.

The beds opened are said to have been the Acme "run" near the surface, but probably, as in the case of the Tinsman quarry, the Albion "run" appeared below the present water level. The strike and dip of the strata are N.80°E. and 39°S., but toward the south there is a steepening to a dip of 42°S. Cleavage strikes due east and dips 28°S. Grain trends N.40°W. and dips 28°S. Several N.50-55°E. joints dip 75°N. at the surface, but become more vertical with depth.

History and development.—The history of the quarry is not known. It was last operated by the Plainfield Slate Company. At present the equipment includes a factory or mill, but no shanties.

Judging by the material on the dump, the products were mill stock and roofing slate.

6. TINSMAN QUARRY.

Location and dimensions.—This quarry lies about 600 feet east of that just described and on the north side of the highway. It is a nearly square opening, being approximately 300 feet long in each direction. The greatest depth is 245 feet; the sides are all vertical except that to the southeast, which falls off steeply. The only working level is in the bottom of the opening.

Geology.—The glacial overburden varies from place to place but attains a maximum thickness of about 15 feet, though the slate has decayed to yet greater depths. The drift is clayey, with boulders up to 1.5 feet in diameter.

This quarry is opened in the Acme "run," but at a depth of about 50 feet on the north wall the Gray bed of the Albion "run" appears. The same recognizable bed is seen in the bottom, somewhat south of the middle of the quarry.

The structure in which the opening is made is the lower limb of a

northward overturned anticline having an almost horizontal axis. The beds at the surface strike N.75°E., and dip 37°S., while in the bottom of the quarry the strike is N.73°E. and the dip 32°S., a decline in dip with depth, whereas the cleavage dips more gently than the beds. This structure is complicated by transverse folding, however, for both at the surface and in the lowest part of the hole, the beds along the eastern wall strike N.73-75°E., whereas on the western side they strike N.88-75°W. As the strikes of both beds and cleavage take this turn, there is a suggestion that the transverse folding was accomplished in part later than the development of the slaty cleavage, possibly by much movement along the open bedding planes.

Cleavage dips 20° southward. The grain trends N.50°W., and dips uniformly about 70°E.

Jointing was studied with care and it was found that the joints do not well fall into any single system, but possess rather a radial pattern, such as might be expected if the transverse folding mentioned had been induced more recently than the cleavage (see p. 181).

History and development.—This quarry, also called the Penn-Bangor, was first opened by C. Miller in 1901, the company being incorporated under the name of the Penn Bangor Slate Company. In the same year it was taken over by M. L. Tinsman and Company, the chief stockholders being Messrs. M. L. Tinsman, R. T. Cowling, and J. Rotzell. In October, 1924, after a protracted strike affecting the entire Northampton County district, the business changed hands, ownership being transferred to Jas. W. Williams, Arch. M. Jones, and Wm. A. Smith. The company is capitalized at $75,000.

The equipment consists of a mill and the usual quarry machinery. The mill has six saws, three planers, two rubbing beds, and a grindstone. A mechanical drill press is used. Four shanties were in operation when the quarry was visited in 1923, one shanty being set on the level with the factory, so as to utilize the refuse blocks directly.

Three masts serve the hole.

The production includes roofing, blackboard, structural and electrical slate.

7. ALLEN QUARRY.

Location and dimensions.—This opening is 3,000 feet almost due south of the Wind Gap post office and 800 feet east of the Nazareth-Wind Gap highway. The opening is small, measuring about 65 by 50 feet, and is filled with water, so that only about 4 feet of slate are seen. The dump lies south of the hole.

Geology.—This quarry is reputed to be in the Grand Central "run." The beds strike N.65°E. and dip 85°S., but the dip flattens downward, declining to 60° in a vertical distance of only four feet. The suggestion is that the exposure is on the south limb of a northward overturned

syncline. The cleavage strikes N.80°E., and dips 20°S. The grain trends N.37°W., with an eastward inclination of 80°.

History and development.—Mr. Allen, who owns this property, says that the quarry was worked about eight years ago; and was carried to a depth of 35 feet. It yielded good roofing slate, though no big beds were found. Operations were discontinued because of scarcity of labor.

8. KINNEY QUARRY.

Location and dimensions.—This small opening lies about 1200 feet S.80°E. from the Woodley House in Wind Gap. It is approximately 80 feet square and 15 feet deep to the water level; the upper 5 feet are soil and badly weathered slate. It is said to have been 35 feet deep.

Geology.—Mr. Kinney of Wind Gap, the present owner of the property, who opened the quarry, says the beds exposed were supposed to be in the North Bangor Number 3 "run." Two big beds were encountered, of which each was 12 to 13 feet "long," measured along the cleavage plane, the two being separated by 18 to 20 feet of thin beds.—a sequence corresponding moderately closely with that of the North Bangor No. 3 beds as measured at Bangor.

The dip of 43°S. was found to be constant through the full depth of the quarry, according to Mr. Kinney. The beds strike N.70°E. at the surface. The cleavage strike is N.73°E., and the dip is 18°S.; the structure thus appears to be on the south limb of a syncline with southward dipping axial plane.

History and development.—This quarry cannot have produced much slate. It was opened about twenty years ago by Mr. Kinney and later leased to a Mr. Evans and his associates. There is no machinery on the property.

The production consisted wholly of roofing slate.

9. PHOENIX QUARRY.

Location and description.—The Phoenix quarry is about 1,200 feet east of the Wind Gap highway and half a mile south of Alpha, as the crow flies. It is 350 feet long in an easterly direction and about 200 feet wide northward. The lowest level has a depth of 260 feet. In its western half the quarry is worked on a sub-level having a depth of 200 feet. A small sub-level, with a depth of 190 feet below the surface, lies against the southern side, near the southeastern corner of the main working level. Another still higher level lies west of that last described, at a depth of 80 feet below the surface.

The extensive dump parallels the quarry along its southern side.

Geology.—Cutting through an overburden of 3 feet of weathered slate and till, this quarry is opened in beds that lie south (i. e. under)

the Acme "run." At least three big beds are found, each over 4 feet thick.

At the surface the beds strike N.78°E.; they dip vertically along the southern side of the quarry, 68°NW. along the northern edge. Downward the beds usually decline in dip, but retain their northward inclination, for in the sub-level the dips are 38° along the north wall, 39 and 41° farther south. The structure is, thus, that of the north limb of a syncline, the axial plane of which emerges near the southern edge of the opening and dips south at an angle estimated to be 15°.

Cleavage strikes are almost uniformly N.70-72°E. The grain trends N.57°W. and is vertical. The predominance of N.60-80°E. joints having steep dips is very conspicuous (see Plate XXVII, B, p. 181).

Cross-bedding is commonly seen in the sandy beds; wherever observed it dips westward.

History and development.—The quarry is operated by the Phoenix Slate Co., of Wind Gap. It is said to have been opened about 30 years ago. Many small operators worked the property in turn, but in 1907 it passed into the hands of the present owners. The surrounding land is owned outright by the operators.

Two mills are installed. One of these is equipped with five saws, three planers, and three rubbing beds. A saw and planer for sizing and shaving waste pieces cut from larger blocks are placed at the end of the mill beyond the rubbing beds. A drill table is equipped with multiple augers.

The smaller mill contains five saws, two planers, and two rubbing beds, as well as a Vermont buffer, a Roberts multiple-head buffer, and a drill table.

At both mills saws are used instead of carborundum wheels, for trimming the smaller slabs.

The waste material from the mill is made into roofing; only one shanty was in operation in August, 1923.

Five masts serve the quarry.

The product consists almost wholly of milled material, including especially large quantities of billiard table tops.

10. HELLER QUARRY.

Location and dimensions.—A small pit lies 700 feet north of the Phoenix quarry, across the road from the latter. This opening is 25 feet deep to the water and may be 30 feet deeper below water level, to judge by the size of the dump. It is about 70 feet square at the surface. A small dump is built up to the south.

Geology.—Several slate men assert that the opening exposes a part of the Albion beds, as might be expected; Mr. Spry of Bangor says it yielded the Front big bed. Of the beds seen, none exceed two feet in

thickness. The strata strike N.78°E., and dip 75°NW. at the water level. At the very surface the badly weathered beds appear to be vertical, as though the axial plane of the fold seen in the Phoenix quarry were almost horizontal.

History and development.—This quarry, truly little more than a prospect, was opened by Mr. Kinney, at the expense of Dr. Heller of Wind Gap. A small production of roofing slate is reported.

11. IMPERIAL QUARRY.

Location and dimensions.—This large quarry is 600 feet west of the Phoenix quarry and about 2,000 feet due south of Alpha. It is rhomb-shaped and measures 300 feet northwestward and 450 feet northeastward. The depth exposed above water level was about 7 feet in 1923. A large dump, which suggests a total depth of at least 150 feet, has been built up to the south.

Geology.—The only overburden consists of from 2 to 7 feet of weathered slate. Very little of the slate is visible above the water. The beds worked are about the same as those in the Phoenix quarry, as the two quarries lie along the same line of strike. In the Imperial quarry the beds strike N.70°E., and dip 45°SE. in the northeast corner, but the turn in dip is apparently so sharp that in the northwest corner the dip is to the northwest. The syncline thus shown fits in with the structure seen in the Phoenix quarry, where the surface of the ground does not quite rise to the level of the axial plane.

In the northeast corner of the quarry the cleavage strikes parallel with the beds and dips southward 20°. Grain trends N.57°W.

History and development.—From 1905 to 1910 this quarry was operated by Reuben Harding of Pen Argyl. Then it passed into the hands of George Albert and James Powell of Bangor for a year. Thereafter it remained idle.

Recently it is said to be developed by Mr. Thomas Peters of Wind Gap, who is stripping along the east side.*

Four masts still remain on the dump, the cables crossing the quarry from the southeastern side. An old mill, now considerably weathered, stands on the dump; it is equipped with two planers, six saws, and two rubbing beds. There are also various accessory buildings.

Judging by the material on the dump, the main production consists of structural slate, blackboards, electrical, and roofing slate.

12. ACME QUARRY.

Location and dimensions.—This is the more southerly of the two quarries located about 1,250 feet due southwest of the Alpha station. It is an elongated rhomboid in ground plan, the longer dimension extending 400 feet northeastward, the shorter 200 feet northwest. The

* Operating in 1926 by Thos. Peters and Wm. Evans under the name of Imperial Slate Blackboard Company.

entire western half of the hole is abandoned and is being used as a dump. The eastern part is on two main levels, the upper only being worked. The upper level has a depth of about 70 feet, but rises northward until it is only 35 feet below the surface. The bottom of the lower level has a depth of 105 feet.

Besides being dumped into the bottom of the quarry, much waste slate is piled up along an incline to the northwest of the working levels.

Geology.—The slate is covered with an overburden consisting of poorly assorted clay and boulders, some of the latter being as much as six feet in diameter. This overburden is thickest in the south, where it amounts to 8.5 feet of drift, but thins northward. The weathered slate that lies immediately under the overburden on the northeast side of the opening shows marked overturning of cleavage toward the south, due to creep; this has already been described in the section on the effect of topography under "Economic Geology of the Slate" (p. 101).

In the Acme quarry the beds worked constitute the Acme "run" and correspond in part to those of the upper part of the Tinsman quarry. They are softer than many of the other beds of the Albion quarries. Toward the southern edge of this sequence are two exceptionally big beds, the more southerly of which is used for blackboards and electrical slate, while that to the north makes excellent blackboards and structural material.

At the surface the beds dip 85°S., and strike N.70°E., but as they are followed northward it is seen that the dip becomes 80°NW. In the upper (working) level a change to the same effect is observed; the beds at the southern edge of the level dip 85°N., although those in the northern part dip only 46°N. It is clear from these observations that the quarry is on the lower limb of a northward overturned syncline, very probably the structure described in the Phoenix quarry.

Cleavage varies, but generally strikes north of east and dips 15-30°E. Grain trends N.30-45°W., dipping N.80°.

In about the middle of the upper (working) level a small fault striking N.60°W. and dipping 35°S. is seen. The displacement of this fault nowhere exceeds 3 inches, and it would scarcely be noticeable, did it not cut a "loose ribbon" or calcareous bed. When the slate is stripped from this, it is seen to project northward above the fault plane. The fault trace can be seen on the wall overhanging the lower level on its eastern side, but the displacement rapidly declines so that the fault is finally lost to view.

A feature in the jointing in this quarry is the large number of joints striking northwestward (see Plate XXVII, p. 181).

History and development.—The Alpha and Acme quarries were both once owned by the Alpha Slate Manufacturing Company, the president of which was J. N. Hoffman. They were operated by Wm. Winsboro

and a Mr. Shull of Stroudsburg; in 1885 operation by these partners was discontinued and the quarries came into the hands of the Alpha Slate Manufacturing Company. Then the lease was taken over by C. N. Miller and Wm. Bray. In 1917 the operations were begun by a new firm, the Colonial Slate Company, owned by the Spry Brothers of Bangor.

A small mill on the property is equipped with three rip-saws, a buck-saw, two planers, a rubbing bed, a 4-speed, geared drill press, a Roberts buffer, an emery cutting wheel used in lieu of a saw and for bevelling. Three shanties were being supplied with material for roofing slate in 1923.* The products are structural slate, blackboards, roofing material, and especially electrical slate. Two cable hoists give access to the quarry.

13. ALPHA QUARRY.

Location and dimensions.—This L-shaped quarry lies due north within a stone's throw of the western end of the Acme quarry. It measures about 200 feet in both directions. Water now comes to within 10 feet of the surface and a depth of only 5 feet of solid rock shows above the water. Much of the old dump on which the mill of the Acme quarry is located is material from this quarry.

Geology.—The opening shows from 5 to 12 feet of weathered slate and glacial material.

Operations uncovered the Albion "run," of which the Gray bed is said to have appeared near the middle of the southwest side, where a shoulder of the wall projects into the quarry; even the Hard Front big bed was found at depth.

The beds exposed strike N.58°E. and dip NW.65°; the dip is reputed to have declined with depth. The cleavage could not be measured, but apparently resembled that of the Acme.

History and development.—The history of operations on this property has already been given in the description of the Acme quarry. The Alpha quarry was the earlier worked. It has been abandoned for several years. In 1926 it had been drained and was producing slate.

14. QUARRY.

This is a very small trench showing only a thin glacial overburden and a few slate chips. Nothing is known as to the rock underground at this locality.

15. QUARRY.

Location and dimensions.—About 600 feet east of the Acme quarry and separated from it by a patch of woods is a small, almost rectangular opening, apparently long deserted, measuring about 100 by 200 feet, the longer dimension extending northeastward. Water floods

* This mill was burned down in October, 1925, and a well-equipped mill now stands north of the Alpha quarry.

the hole, standing within 5 feet of the surface. The maximum depth is said to have been 70 feet.

Geology.—This opening shows about 5 feet of overburden along the north side; it consists of clay, slate chips, and occasional boulders. The beds exposed at the surface must be in the lower part of the Albion "run."

The beds, though poorly shown, seem to strike N.60-65°E., and dip 75°NW. The cleavage could not be measured but dips gently south. Grain trends N.40°W. and is vertical.

History and development.—According to Mr. M. J. Spry of Bangor, this quarry is part of the Wagner and Osterstock estate.

This quarry was opened in 1913 by Russell Pritchard, George Albert, James Powers, and A. M. Pass of Bangor. It was operated for about two and one-half years, then abandoned.

The equipment consists of an old mill shed, largely dismantled, with a few pieces of machinery remaining. A part of an old pump and a rusted boiler are still in place on the property. Two pulleys and cable lines are seen at the south side of the opening.

16. ALBION SUPERIOR QUARRY.

Location and dimensions.—This opening is 200 feet east of that last described. It is a nearly rectangular hole, about 200 feet wide in a northeast direction and 350 feet long toward the northwest. It is filled with water, but along the northeast and southwest sides overburden and rock are seen projecting above the water level. The depth is reputed to be 125 feet.

A considerable dump of waste material has been built up south of the opening.

Geology.—The overburden, which has a thickness of 3 feet or more, is of clay, slate chips, and occasional faceted quartzite boulders. It attains a maximum thickness of 15 feet, being heaviest on the eastern side of the quarry.

Beneath the overburden limited outcrops of slate are exposed. Though no beds are recognizable with certainty, it is believed that this opening should show the Albion "run" from end to end at the surface and perhaps even extend a short distance into higher beds; this hypothesis is in agreement with the opinions of the quarrymen.

In the one exposure where observable, the strike and dip were N.61°-E., 76°NW. Cleavage and grain were not measured.

History and development.—Quarrying was begun here in 1912 by the owners of the Wagner and Osterstock estate, who still retain the land; some slate was then removed by Joseph Kellow and Albert Rundle of Pen Argyl, under the name of the Bangor Slate Manufacturing and Supply Company. In 1917 operations ceased.

The Amalgamated Slate Company of Easton now has a lease on the property and had begun in 1924 to pump out the water, preparatory to further quarrying.

17. STODDARD QUARRY.

Location and dimensions.—This opening lies about 400 feet east of the Albion Superior. It is irregular in shape, being about 300 feet long northwestward by 200 feet northeastward. Twelve to fourteen feet of overburden are seen above the water with which the bottom is filled. The opening cannot be deep, as almost no slate is seen on the dump.

The material removed lies piled up at the northern end of the quarry.

Geology.—The heavy overburden is the conspicuous feature at this quarry. It has a thickness of 12 to 14 feet, being deeper on the east. Taken in conjunction with a similar eastward thickening of overburden in the Albion Superior opening, this suggests a pre-glacial stream valley not far east of the Stoddard quarry.

The surficial material consists of sand-free clay bearing boulders that vary in size up to one foot in diameter; the latter are quartzite or conglomerate, with occasional flatter pebbles of red, micaceous Catskill sandstone. They are generally subangular or faceted, but no striae were seen. They are, however, clearly glacial in origin.

On the northeast side of the quarry a small exposure of slate shows a bed about 9 feet "long" measured along the cleavage, with thinner beds on either side. This may well be the outcrop of the Genuine big bed of the Albion "run," which should be exposed here. The stratification strikes N.51°E., and dips 85°S. The cleavage was not measured, but dips gently south. The grain trends N.44°W., dipping 60°W.

History and development.—The opening was made in 1917, but little was removed except the glacial cover. On the whole, this should represent a favorable location for operating, except in that, as depth is reached, the beds will probably dip more gently, "running fast toward the mountain", as the quarrymen put it.

Nearby opening.—East of the opening about 300 feet lies a small quarry not examined. It was described to the writer by some of the slate operators, who say that it entered the Albion "run". The authority for this statement is competent. The opening was made in 1915 by the owner of the property, Mr. Glosser.

18. DICK QUARRY.

Location and dimensions.—This small opening lies 1,200 feet N.70°E. from the Grand Central quarry, hidden in woods west of the Delaware, Lackawanna, & Western Railroad. It measures 50 feet square and

water fills it almost to the top. Its depth was probably not over 35 feet.

Geology.—Only a small area of slate, with poorly defined bedding, shows above the water. The strike is N.50°E., and the dip is estimated to be about 8°SE. The slate exposed was apparently in the upper part of the Bangor beds.

History and development.—This opening was made in 1900 by Thomas Dick and George Mutton, more as a prospect than as an actual quarry. It is probably one of the oldest quarries in the Pen Argyl region and has long been abandoned.

19. MARTIN AND HARDING QUARRY.

Location and dimensions.— About 500 feet east of the Grand Central quarry is an elongated opening measuring 250 feet northwestward by 100 feet northeast. Its depth to water is 20 feet, but a large dump has been built up to the north and, judging by the amount of waste here, the depth must have been 100 feet.

Geology.—The beds exposed are said to be part of the Old Bangor "run". They are thin, but cleavage is well developed and the opening was promising.

The beds at the southern end strike N.50°E. and dip 62°S.E. whereas at the north end, the dip is 45°S. They are thus on the north limb of an anticline, the axial plane of which dips south. The cleavage strikes N.80°E., and dips 20°S. The grain is parallel with the sides of the quarry, trending N.40°W., and stands vertical.

History and development.—Mr. Spry of Bangor states that this quarry was opened in 1910 on the Wagner and Osterstock estate by William Harding and Isaiah Martin. It was abandoned in 1912 because of the reduced "length" of the beds,—the cleavage and bedding planes intersecting at a high angle, and the beds probably being thinned considerably by tight folding, besides.

The product was mainly roofing slate.

20. DONEY'S OLD QUARRY.

Location and dimensions.—This small opening lies 200 feet south of the last and on the south side of a secondary road. Its maximum depth to water is 15 feet, but it must be at least 60 feet deeper, to judge by the size of the dump that lies east of it.

Geology.—It is said that the 9-Foot big bed of the Old Bangor "run" was quarried here. One bed near the southern end is 3.5 feet thick. The strike is about N.60°E., and the dip approximately 60°S. The quarry is thus on the same structure as described for the Martin and Harding quarry. The cleavage strikes N.60°E., and dips about 10°S. Grain trends N.40°W.

Some good blocks of slate are seen on the dump. "Rusting" (brown

staining with iron oxide) is not much in evidence. The beds seem to be thin, however.

History and development.—Quarrying was begun here in 1908 by Mr. Fred Doney of Pen Argyl, operating for the Doney Slate Company, and ended in 1910. No machinery appears on the dump. The product must have been chiefly roofing slate.

21. GRAND CENTRAL QUARRY.

Location and dimensions.—This large opening lies along the Delaware, Lackawanna, & Western Railroad, about three miles south of the station at Pen Argyl. It is in the valley of Little Bushkill Creek and the stream itself flows through the quarry. The main part of the opening is almost in the form of a rectangle measuring about 250 feet square, but along the northwest wall a smaller rectangular area 50 feet square projects northward from the main hole.

The larger part of the opening is filled with water, but near the east corner walls of slate rise 70 feet above the water level. The surface of the ground, now mainly removed by quarrying, thus dipped sharply northward. The maximum depth said to have been attained in quarrying is 175 feet.

A large dump is built up south of the quarry and on this several shanties, partly demolished, and various mill buildings are still to be seen.

Geology.—As the slate is now nowhere accessible to detailed measurements, the statements of the quarrymen as to the beds worked were accepted. Mr. M. J. Spry of Bangor reports that the small northward projection from the main quarry entered the Old Bangor "run" and that the main opening is in the Grand Central "run", in which are two big beds, the upper 4 and the lower 8 feet thick, separated by a thickness of 25 feet of smaller beds.

At the surface in the eastern corner the beds strike N.75°E. and dip 25°N. The dip is said to have changed sharply, however: at a depth of 150 feet or so the dip is southward; immediately lower down the direction of dip was once more reversed and the strata inclined to the north.

This sharp double reversal in dip was accompanied by the opening of cracks and clefts and by the development of irregular cleavage. The openings formed were heavily filled with quartz and calcite, very deleterious to the slate. When this structure is compared with that in the Martin and Harding and Doney's Old quarries to the west, it is seen that the latter must be on the upper limb of a northward overturned syncline with almost horizontal axial plane; the lower limb of this structure is represented by the northward dipping beds at the surface in the Grand Central quarry. The latter, being topographically

lower, represent a stratigraphically somewhat lower horizon. These relations are shown in Figure 36.

The cleavage strikes N.60°E., and dips 25°S. The grain, which parallels the southwestern edge of the quarry, strikes N.43°W.

History and development.—This quarry was opened by R. M. Jones, the "founder of Bangor," about 1880. After some operation, it was sold to Thomas D. Moulds of Philadelphia. Moulds took out some slate and then leased the quarry to a company of five stockholders. Following further development, the lease was sold to E. J. Johnson of New York

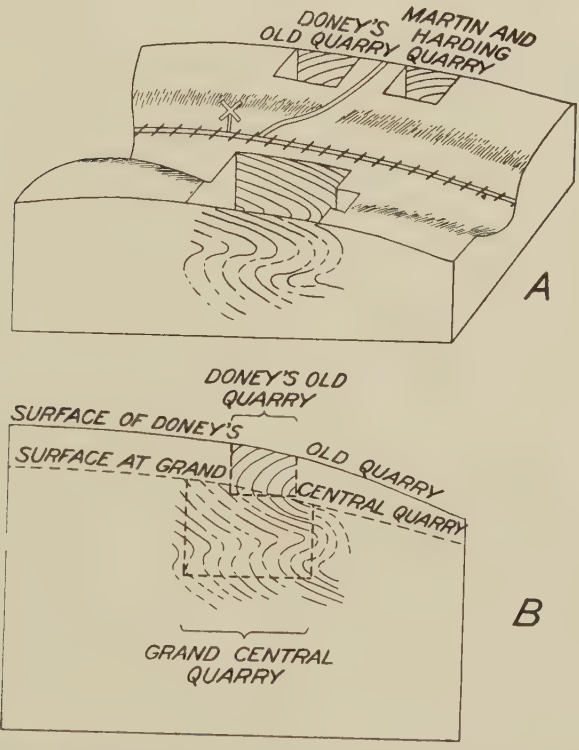


Figure 36. A, Block diagram to show relations of quarries at Grand Central; view westward from the Grand Central quarry; B, projection of Doney's Old quarry upon plane of grain in Grand Central quarry, to show true structure.

City in 1902. Johnson operated the quarry until 1913, when it was sold to John Jones, David Price, and Llewelyn Jones, who continued production for a year. Finally the quarry passed into the hands of James H. Munro, who attempted to cut slate into tiles and cement these on tar paper roofing; his company operated under the name of the Inlaid Slate Company. Work was stopped at the quarry in about 1916, but the Inlaid Slate Company still retains the lease.

A few shanties remain on the dump and two cable lines are stretched across the opening from the southeast side.

The production was roofing slate and millstock. In the upper part of the quarry, above the point at which the strata turn and dip south, good blackboard slate was obtained.

22. SMALL GRAND CENTRAL QUARRY.

Location and dimensions.—This small opening, measuring 30 by 70 feet, with its longer dimension extending northward, lies about 300 feet due southeast of the large Grand Central quarry. It is a shallow hole, and much of it is filled with waste.

Geology.—One conspicuous bed having a thickness of 2.5 feet is seen. The strata here are in the lower part of the Grand Central "run" but no beds could be definitely correlated with the known sequence. The strata are probably continuous with those seen in the northeast wall of the Grand Central (see Figure 36).

The strike in this opening is N.85°W., and the dip is 11°NE. Cleavage strikes N.85°E. and dips 32°SE.

History and development.—This small hole, the history of which is much like that of the Bangor Central opening, was worked in 1905 by E. J. Johnson of New York City. It is a part of the same property as the larger Bangor Central quarry.

23. QUARRY.

Location and dimensions.—A small prospect hole, of irregular shape, lies in a field south of the road, 1,600 feet S.65°E. from the Grand Central quarry. It is roughly arcuate in ground plan and 50 feet long; its depth is 10 feet. Waste from the hole is piled up about it.

Geology.—The slate appears to be of fair quality, but no thick beds are seen. The strike is N.60°E., and the dip 10°NW.; the cleavage dips 12°SE., and strikes parallel with the beds.

History and development.—This is merely a prospect. Nothing is known of its history.

24. DONEY QUARRY.

Location and dimensions.—About 400 feet south of the highway between Wind Gap and Pen Argyl, and three-quarters of a mile east of Alpha is the Doney quarry. At the surface the opening is 300 by 125 feet in size, the greater dimension extending N.75°E. There are two working levels, of which the upper is 110 feet deep, the lower 150 feet beneath the surface; the sheer wall between the two divides the quarry into northeast and southwest halves.

A large dump has been built up south of the opening.

Geology.—An overburden of weathered slate and of slate chips set in clay is all that lies above the slate. The depth from the surface to

bed rock is from 3 to 8 feet. The cleavage planes at the surface of the slate show the usual downhill creep to the south.

The quarry is opened in the lower part of the Albion "run", the Gray bed appearing on the lowest working level about ten feet south of the northwest quarry wall. As the beds dip southward the Gray bed is not so far south in the upper level, but instead the greater part of strata exposed are lower down in the Albion "run". The Gray bed lies just within the northwest quarry wall at the surface.

On top the beds strike N.68°E., and dip 71°S., but the dip declines southward, for it is 71°S. at the northern edge of the opening and only 68° at the southern side. As depth is gained the dip increases to 75° on the upper level and even 81°S. on the lower level. The structure is thus, the upper (southern) limb of a syncline with axial plane dipping south. Structurally this is in harmony with the New Diamond, Parsons, and Albion Vein quarries.

The cleavage strikes N.75-85°E., and dips 15-18°S. Grain trends N. 50°W., and dips vertically.

Three definite systems of jointing are recognizable. One strikes N.55-60°W., and dips 32-40°S.; these joints commonly stop at "loose ribbons." A second set strikes N.80°W., with highly varied dips. A third set strikes N.55°E., with dips varying from 80°S. to 80°N. Not uncommonly these joints are seen to unite by an increase in dip of the lower joint. The joints are shown on page 181.

History and development.—This quarry was opened in 1919 by the Doney Slate Company, a corporation formed by Mr. Alfred Doney and his sons. Operations are progressing under a long-time lease, the property belonging to the Hugh L. Davis estate.

A well equipped and carefully planned mill is located west of the quarry.[110] At the time of inspection some of the slate was being transferred to the mill of the New Diamond quarry for finishing.

The products are blackboards, electrical slate, structural slate, and roofing slate.

25. NEW DIAMOND QUARRY.

Location and dimensions.—This opening lies about one thousand feet northeast of the last. A road connects the two quarries. The New Diamond quarry is 125 feet wide in a northwesterly direction, and 450 feet long, and approximately rectangular in ground plan. Its greatest depth, attained in the western part, was not measured. This deep portion of the quarry is water-filled and the water surface appears to be at least 200 feet below the surface of the ground; it represents two-thirds of the total length of the quarry. The eastern part was being worked on three levels when visited in 1923, and stripping

[110] See Bowles, Oliver, The technology of slate: U. S. Bur. Mines, Bull. 218, pp. 79-80, fig. 30, 1922.

was being conducted at ground level south of it as well. The depth of the lowest working level is 90 feet; that of the next level is 50 feet; and the topmost level or "piece" is about 15 feet below the surface of the ground. The two higher levels parallel the lowest along the southeast side.

The dump is being built up partly to the northwest, partly near the mill to the west, and much waste material is taken south of the quarry and deposited along the railroad as ballast.

Geology.—The beds exposed are a part of the Diamond "run". They cover most of the sequence from the lowest beds seen in the south wall of the New Diamond quarry. On the lowest level two thick beds, the Genuine big bed of the Diamond "run" and the Red bed, measure respectively 78 and 109 inches along the cleavage. At the northern edge of the stripped surface is another thick bed.

It is said that these beds are more "tender" or brittle than those of the Albion "run" and hence slightly more difficult to quarry. They are also generally somewhat coarser and less uniform in the size of the grains as seen under the microscope.

At the surface the beds strike N.61°E. and dip 63°S., the dip decreasing slightly to the north. The dip also steepens downward, being 63°, 65°, and 70° respectively at depths of 15, 50, and 90 feet below the surface. It is apparent that this quarry is located on the same structure as the Doney quarry, the south limb of a syncline, the axial plane of which dips southward.

The cleavage strikes approximately parallel with the beds and dips 12-18°S. The grain trends N.50-58°W., and is vertical or dips steeply east.

Although not as clearly falling into systems, there is yet a strong suggestion of the heavy development of northwest-striking joints similar to those in the Doney quarry (see above). The tendency of joints to merge with each other and with "loose ribbons" is a striking feature in this quarry. Thus, a calcareous "ribbon," bordered by an open crevice and highly striated, is seen about midway on the floor of the lowest working level, and against it many joints stop abruptly.

History and development.—This quarry was first opened by the American Slate Company in 1885; it was operated by that firm until 1900, then lay idle for ten years. In 1910 the Diamond Slate Company took it over. This company is incorporated for $10,000. The chief shareholders are H. A. Miller and Wm. L. Doney.

The mill, located southwest of the opening, is described by Bowles.[111] The Vermont single-head buffers are employed exclusively for polishing the slate blackboards. An emery wheel is used to cut thinner slabs.

[111] Bowles, Oliver: The technology of slate: U. S. Bur. Mines, Bull. 218, p. 80, 1922.

This is one of the few Northampton County quarries at which drilling and broaching finds favor for removing the slate. The process is described in the section of this report entitled "Technology of Slate".

The products are blackboards, electrical slate, and structural material. No roofing slate is made.

26. PARSONS QUARRY.

Location and dimensions.—The Parsons quarry is about a quarter of a mile south of the Delaware, Lackawanna, & Western R. R. Station at Pen Argyl. It lies just north of the tracks of that railroad. It is approximately rectangular in ground plan, measuring about 350 by 175 feet; the longer sides trend about N.60°E., parallel with the beds. Work is conducted on four levels, of which the depths are 530 feet, 380 feet, about 315 feet, and 250 feet. The southwestern part of the opening is occupied by the almost square upper "piece"; the 380-foot level forms the northwestern half of the remainder; the 315-foot level lies between the deepest and shallowest working levels. In addition stripping is being conducted along the southeastern side of the hole, between the quarry and the railroad.

All waste slate is dumped east or north of the opening.

Geology.—Along the southeast side, this quarry shows an overburden of:

	Feet
Earth and grass roots	1
Clay	2
Boulders of quartzite and slate chips in clay	1.5
Badly weathered slate, chips above, larger blocks or continuous stone below	4
Slightly weathered, rusty slate, passing into good gray slate below	5

The "back" of the quarry lies along a "loose ribbon". The beds exposed between this and the "front" of the quarry consist of some of those seen in the New Diamond quarry and of other beds lying higher in the sequence and reputed to have been found in the Jackson Bangor No. 4 (Diamond) opening.

At the surface the beds strike N.57-61°E., and dip about 63°S. On the uppermost working level the dip increases to 73°S. Still lower, on the 380-foot "piece," the beds dip as much as 87°S. At the greatest depth the dip is reversed and the beds incline northward 57°. The structure is thus the same as that of the New Diamond quarry, but the greater depth has carried the work below the synclinal axis. In the upper level the Red bed, the Genuine big bed (Diamond "run"), and the Johnny Knack bed are especially thick and valuable.

The cleavage varies somewhat in strike, readings having been ob-

tained between the limits N.71°E. and N.84°W; the dips are low, averaging 10 to 12°S. Grain trends N.45-50°W., and is vertical or inclines steeply eastward.

Jointing was studied with care wherever accessible. At the surface a long, conspicuous joint is seen in the northwest wall. Below this a series of joints, striking northeast and apparently dipping about 60°S., begins and continues downward. The wall being inaccessible, the strike and dip of these fractures can only be estimated. Above the one conspicuous joint mentioned is another system dipping northwest. It is unfortunate that these joints cannot be measured.

The lower "pieces" showed almost no jointing, but the highest working level exhibits two systems, one suggesting in its strike the N.75°W. joints of the Doney quarry, the other trending approximately N.50°E.

History and development.—The quarry was opened in 1892 by a partnership consisting of Henry, David, Samuel, and Thomas Parsons, all brothers and each owning a quarter of the stock.

In 1908 Henry Parsons absorbed the interests of his brothers, and the company was incorporated for $45,000 in 1910. Some of the stock was taken by Wm. H. Parsons and M. L. Parsons at that time. In 1919 Mr. Henry Parsons retired and the stock came into the hands of Messrs. Wm. J., M. L., Lucas, and Francis H. Parsons, and Mrs. Stella P. Hill.

The mill equipment is housed in four buildings. One shed has two saws for trimming blocks to a size acceptable in the roofing shanties. In a second building much of the structural slate is prepared; the equipment in this mill consists of 4 saws, 3 planers, and a rubbing bed; grapples on booms are used to move the slate from table to table or rubbing bed. The third shed is the blackboard factory, which is equipped with 3 rubbing beds, 2 multiple buffers, and an emery wheel that is used as a trimming saw; on either side of the blackboard mill are stock sheds. The fourth building is the main structural mill and is equipped with 3 rip-saws, 4 planing machines, a rubbing bed, a small Vermont buffer, and an emery wheel, traveling at 1,400 revolutions per minute, for sawing blocks; two grapples on booms are used to transfer slate from the sawing tables to the planers.

This company also operates a slate pulverizing and grinding mill, described by Bowles.[112]

The products of the Parsons Brothers Slate Company include roofing slate, structural material, electrical slate, grave vaults, blackboards, slate granules and slate powder.

27. ALBION VEIN QUARRY.

Location and dimensions.—The Albion Vein (West Albion or Stoddard) quarry lies 300 feet south of the Parsons quarry and south of

[112]Op. cit., p. 114.

the Delaware, Lackawanna, & Western Railroad. In general plan it is quadrangular: the northeast and southeast sides make a right angle with each other, as do the northwest and southwest sides, but the angle at the northern corner is obtuse and that at the southern acute. The longest dimension, that along the southwest side, is about 500 feet. The greatest width, from the middle of the southwest side to the east corner, is approximately 400 feet.

This is the second deepest quarry in the region, being exceeded only by the Parsons quarry, and attaining a maximum depth of 500 feet. The work during the summer months is confined to the lowest level, but during the winter, work proceeds on the several benches; these are at various depths along the northwest wall, the lowest being 210 feet below the surface. Stripping along the southeast side was in progress in 1924, the object being to enlarge the area opened.

The dump is built up to the south and southwest of the hole, where are located the mills and shanties.

Geology.—Structurally this quarry is situated similarly to the Parsons quarry, but in beds lower in the sequence. The Albion "run" has been opened, almost from top to bottom. The "loose ribbon" making up the northwest wall is said to be in the Jenny Weeks bed, and the Front big bed, which is the southmost or lowest stratum in the Albion "run," lies just south of the southeastern quarry wall; about 40 feet north of the east corner, the Gray bed comes to the surface.

Near the top of the quarry the beds strike N.60°E., and dip 37-44°S., but as they descend a vertical attitude is acquired at a depth of about 250 feet. Below this point the beds dip north, to a depth of 350 feet beneath the surface, where the vertical is resumed for a short distance. Then the dip is north, vertical, and southward again, but very steep, and at the top of the working level a steep southward dip (85°) is seen. At the lowest point, however, the dip is clearly 46°N.

The cleavage strikes N.60-70°E., and dips 13-20°S. Grain trends N.52°W.

Two rather unusual structural features are seen in this opening. The "back" (northwest) wall appears to be formed by a bedding plane. Close inspection, however, shows this to be a bedding-slip fault of the type already described (see Bedding slip faults, on p. 65). syncline, a far smaller arc than is formed by the fault plane itself. Against the fault plane the cleavage is curly and mashed, and on the northern side it tends to have a high southward dip as the fault is approached, suggesting drag. Beneath the fault numerous closely spaced, almost vertical joints, partly calcite- and quartz-filled, are seen. The fault gouge is 2-3 feet wide, with quartz and calcite filling. The striae where seen dip almost vertical and extend southward parallel to

the bedding dip. Actually there is a zone made of two such fault planes, close together (see Plate XXX, A, p. 209).

In the north corner of the lowest level is a fault of a different nature. This strikes N.25°E. and dips 35°SE. In this case the movement was probably horizontal, the east side moving north, and the distance moved was not more than two feet along the plane.

The outstanding feature of jointing in this quarry is its close resemblance to the systems of the Parsons quarry. The regularity in the jointing here favors quarrying, because the removal of the slate in rhombic blocks is permitted. Some of the northwesterly joint surfaces bear pyrite lenses (For the joint pattern, see Plate XXIX).

History and development.—The Albion Vein quarry was opened in 1902 by Hugh L. Davis, and then passed into the hands of the Cleveland Slate Company, of Cleveland, Ohio. This corporation sold the lease in 1908 to the Albion Vein Slate Company. The larger stockholders in the Albion Vein Slate Company are Messrs. George, Arthur, Harry, Fred, and Frank Stoddard, H. L. Boyd, and H. L. Young. The company is incorporated for $80,000.

The two mills on the property are south of the opening. In one the equipment consists of 5 saws, with tables 10.5 feet by 6 feet, 4 planers, 1 rubbing bed, 2 carborundum wheels, so arranged as to be used in sharpening the saws, and 1 whet stone, for the planer knives.

This machinery is driven by two parallel shafts, which are themselves belted to a central drive shaft. The power is electricity.

Instead of a traveling crane and track, a gallows that turns on its vertical axis and bears a pulley and grapple is used to move the slate blocks from table to table. Such an arrangement operates more rapidly than a crane like the Shepard track crane, but places the slate less exactly.

The second factory is a finishing mill. Two large sawing tables (10.5 by 12 feet and 8 by 10 feet) are situated just outside the door of the mill. Within are 1 small sawing table and saw, 1 planer, 3 rubbing beds, and 2 buffers.

Here also are stock sheds and a wood saw for crating. The power is electricity.

When visited in 1923, 14 shanties were in operation.

Six steel masts in excellent condition are used for the cableways. The landing is on the dump south of the quarry.

The production includes roofing slate, all varieties of mill stock and structural material, and blackboards.

28. QUARRY

Location and dimensions.—Two small quarries lie about 1,400 feet S.70°E. from the Albion Vein quarry, in the field east of the road

that leads past the Albion Vein opening. The larger quarry is 50 by 180 feet, and is virtually rectangular; the longer dimension is toward the northwest. There is water in the bottom and 28 feet of slate show on the walls.

Geology.—The beds are sandy and generally thin, but one of them is about 12 feet thick. Cross-bedding is well developed in the sandy layers, the laminae dipping west. The strata strike N.70°E., and dip 10°NW. on the southern edge, but dip 85°SW. in the northern side of the opening; the structure is thus a northward overturned anticline. As the cleavage strikes N.40°E., and dips 10°SE., it is seen that the structure plunges eastward, a fact further confirmed by the observation that the beds along the axis do actually dip 7° toward the east.

The grain trends N.40°W., and dips 80°E.

History and development.—Nothing is known of the history of this quarry. It has the appearance of having been abandoned at least 10 years ago.

A small dump remains, but no machinery.

Nearby opening.—About 100 feet northeast of the last is a very small opening, showing essentially the same structure.

29. ALBION QUARRY

This large opening is worked by two companies, the Keenan Structural Slate Company, which operates the western half of the quarry, and the Stephens-Jackson Company. The dividing line between the two properties extends from the elbow in the southeastern wall to about the middle of the northwest side, but working agreements permit the companies to operate each on the property of the other. Factory, stock piles, and landing of the Stephens-Jackson Company are on the southern side of the opening, and the mills and landing of the Keenan Company are northwest of the quarry.

Location and dimensions.—The Albion quarry is 2,000 feet south of the Pen Argyl post office and 1,500 feet east of the Parsons quarry, from which its huge dump can be seen rising to the east. It is the largest opening in the district in area and in volume. Rhombic in shape, it has areal dimensions of 600 feet N.45°W., and 900 feet N. 60°E. Its depth varies, as there are several working levels in each of the two parts, but the greatest depth measured is 325 feet below the surface, the depth of the water level in the bottom of the pit.

On the east side the Stephens-Jackson Company is operating on five levels, cut much like a flight of stairs, each lower level nearer the middle of the opening than that above. The successive depths of these levels are: top level, 85 feet below the surface; 2d level, 120 feet; 3rd level, 265 feet; 4th level, 305 feet; bottom, 325 feet. Along the western side the Keenan Company has opened levels at 210 feet, and at the bottom 325 feet below the surface. The operations of the latter com-

pany include work along the northwest wall of the opening just west of the property line.

The hole is partly encircled by a large dump, which begins in the western corner and extends south and east half-way around the quarry.

Geology.—Although the two parts of the opening are separately worked, the geology of both parts is similar and may be described at once. The beds exposed are all in the Albion "run." The Jenny Weeks bed is seen in the northernmost reentrant in the northwest wall of the pit. The Genuine big bed of the Albion "run" is quarried on several levels in the eastern part of the opening. The Gray bed comes to the surface about the middle of the northeast and southwest walls.

Operations in the Keenan half of the quarry have been confined in recent years to the upper beds of the Albion "run," from the Gray bed on; in the Stephens-Jackson half the levels have developed chiefly the middle and lower parts of the Albion "run," although the lowest (4th) working level extends almost to the Jenny Weeks bed.

When the northeast wall is viewed from the southwest side of the quarry, the true structure is readily seen. It is evident that the beds dip south at the surface, become vertical at a depth of about 200 feet, and then turn, so as to dip north. There is thus defined a syncline having an axial plane that inclines gently southward (see Plate XXVIII, A and Figure 15, p. 67). This structure carries on into the southwest wall of the opening.

It was found that the beds are generally thicker on the lower limb of the syncline than on the upper.

In about the middle of the northwest wall, just west of the property line, a reentrant leads northward. The north wall of this step-like reentrant is a very smooth surface, apparently a bedding plane. This smooth surface forms the upper half of the wall; lower down, however, it is broken away, partly by channelling, partly by undercutting. This surface is a bedding slip fault, and has been described under that head in the section on the structural geology of the region.

An interesting fact in regard to the cleavage in this quarry is its curvature. In the upper levels of the eastern half of the opening the cleavage locally actually dips north, yet is not crumpled. The impression of a very gentle arch is conveyed by this departure from the customary southward dip. Elsewhere the cleavage dips gently south (see Plate XXVIII, A).

The grain in the western half of the quarry strikes N. 45-55° W., and is vertical. In the eastern half it swings more northerly, N. 38° W. being recorded. Two very poor observations gave N. 25°W., but their accuracy is doubted.

PLATE XXX

A. Bedding slip fault or "loose ribbon" in north corner of Albion Vein quarry. Fault plane at A; typical closely-spaced vertical joints below it.

B. Bedding slip fault of West Bangor quarry, as seen in northeast wall. Fault plane is to left of A. Beds south (to right) of fault dip steeply south at surface; north of fault the dip is more gentle and north. Note joints on smooth face north of fault.

Joint systems are recognized with difficulty. A set of steeply dipping joints strikes N. 35°E. in the western part of the hole, and their counterparts dipping more gently (70°) north are recognizable in the Stephens-Jackson part of the opening. Higher up the joints in the eastern part of the quarry strike N. 60-75°E., and dip moderately or gently north. The regularity of the joints in these upper levels is striking (see Plate IX, A and Plate XXIX).

History and development.—As stated, this opening, the old Courtney quarry, has been developed in both directions, the eastern part being the property of the Stephens-Jackson Company, the western of the Albion Slate Company (formerly the Keenan Structural Slate Company). Work has continued for 49 years. The property originally belonged to Peter Robertson, from whom the Stephens-Jackson portion was bought for $5,000 in 1909 by the present holders.

The major portion of the stock of the Stephens-Jackson Company is now held by Richard Jackson, Jr., Henry E. Stephens, and Fletcher Turner. The charter for this new corporation was issued in 1907.

The Keenan part of this quarry was obtained by the present owners, under the leadership of Mr. Wm. H. Keenan, through purchase from John Miller of Nazareth; a majority of the stock was controlled by the Keenan estate, and a small part was held by Mr. Charles Miller of Bangor. Since the death of Mr. Keenan in 1923, the property has passed into the hands of the Albion Slate Company, Easton, Pa., the Wm. H. Keenan Estate, and the R. S. Brown Estate. The present capitalization is $200,000.

The Stephens-Jackson Company owns a capacious mill, equipped with four large sawing tables, a small sawing table, 4 planers, 3 rubbing beds, a carborundum wheel for sharpening saws, another such wheel, mounted so as to move over a fixed table, rotated at the rate of 1,400 revolutions per minute, and used for trimming, a buffer, and a Shepard crane. A wide space is left in the middle of the mill, and overhead crane tracks are on either side of this central space; these lead down the length of the mill and permit the ready shifting of the crane. Eleven shanties were in use in 1923.

The production includes all varieties of structural slate, blackboards, electrical slate, and roofing.

The Keenan Company operates two mills. One of these has four large sawing tables and an equal number of planers, two rubbing beds, an electrically driven carborundum wheel for sharpening the saws and planing knives, a small carborundum wheel for bevelling and cutting smaller pieces of slate to the desired shape, and an automatic drill.

A second mill belonging to this company contains 7 sawing tables, 3 planers, 3 rubbing beds, 1 emery wheel for trimming, 1 emery wheel

for sharpening saws, 1 grind stone for sharpening planer knives, 1 wood saw.

A track for a Shepard 5-ton crane runs the length of this mill.

The production of the Keenan Company includes all types of structural slate, electrical slate, and blackboards, with roofing slate relatively less important.

30. JACKSON BANGOR NO. 7 QUARRY.

Location and dimensions.—Southeast of the main part of the town of Pen Argyl are seven openings which have long been known as the Jackson Bangor quarries; older names for this group of openings still persist, however, and some of them are used in this report. The seven quarries are generally referred to by number, the old Pennsylvania quarry, that farthest northeast of the group, being sometimes spoken of as the Jackson Bangor No. 1.

The southwesternmost quarry is designated by the owners the Jackson-Bangor No. 7 quarry. It lies about 1,000 feet east of the Albion quarry and it measures 250 by 300 feet. At the time of these studies the eastern side of the quarry was being stripped for further development, but the main hole is water-filled to a depth of about 150 feet. The dump lies to the south.

Geology.—The quarry was not studied in detail because of its inaccessibility. The overburden is 20 to 35 feet thick and consists of glacial till, with boulders mainly faceted, rarely well rounded, set in a matrix of sandy clay. This till passes downward gradationally into slate chips and weathered slate.

The quarry at the surface is opened in about the middle of the Albion "run." Approximately midway in the northeast side the Gray bed comes to the surface. The opening also yielded the Little Hard big and Genuine big beds.

The strata strike N. 63° E. and dip 46° SE. at the surface. At a depth of about 160 feet the strata are said to have been cut by a fault that is probably the one seen in the lowest level of the Jackson Bangor No. 6 quarry. Below this fault the beds moved northward, carrying, according to one observer, the Little Hard big bed above against the Genuine big bed below, a movement of about 70 feet along the fault plane, in the direction N. 30° W. The estimates of the amount of displacement vary greatly, however, for one quarryman says that the movement equalled the entire thickness of the Albion "run." This fault has been described in the section on the structure of the region.

As in the quarries to the east and west, the beds turn at some depth, so as to dip northwest in the lower depths of the quarry. The cleavage strikes N. 42° E. and dips 16° SE. Grain trends N. 47° W. A well-developed set of joints is seen on the walls; these strike N. 20-30° E. and dip 30° NW.

History and development.—The history and development of this quarry are described in the section on the Jackson Bangor No. 6 quarry. It was first operated by the Jackson Brothers Slate Company, but purchased by the Jackson Bangor Company in 1907.

31. UNITED STATES (JACKSON BANGOR NO. 3) QUARRY.

Location and dimensions.—This quarry lies about 1,000 feet S. 60° E. from the Pen Argyl post office. It is of irregular shape, having had its original form greatly modified by the dumping of material from the quarries to the north and south. The eastern portion extends N. 50° E., and has a length of 800 feet and a maximum width of 250 feet, with numerous reentrants. Westward this is continuous with a rhomb-shaped opening the greatest length of which (600 feet) trends east and west, while the shorter northerly dimension is about 300 feet.

This quarry was largely filled with water when visited in 1924, and the structure of the slate at depth was therefore not visible. The water covers all but the upper 50 feet of slate, rising within 62 feet of the surface of the ground. On the southwest side, however, extensive stripping was in progress, and the hole was being enlarged beyond the dimensions shown on the maps and given above. The material removed by these operations was being hauled up an incline along the northern edge of the opening and dumped back into the hole.

Geology.—As the slate is not accessible at depth, only surface observations could here be made. The glacial overburden is five or more feet thick and resembles that seen at the Jackson Bangor No. 7 quarry.

The opening has given its name to a series of beds which were not accessible to measurement in any of the quarries, the United States "run."

A study of the structure indicates that the beds in general dip southeasterly on the southern (upper) limb of a northward overturned syncline. In the northwestern part of the quarry the beds dip 50° NW. but are probably not overturned. In the middle of the western part the strike is N. 50-65° E., the dips varying between 60 and 80° SE. as the beds are crossed southward. Erosion in this part of the structure must have removed a sharp turn, however, and a slight eastward pitch, for on the extreme eastern edge of the opening the beds are well-nigh horizontal, changing from a dip of 24° SE. at the northeast corner to 37° NW. at the southeast corner, the strike remaining N. 63-66° E. It is quite possible that this marked difference in structure may be due to a fault that cuts across the quarry. This fault is probably the higher one of the two in the Jackson Bangor No. 6 quarry, for the projection of its plane would give it that position. As the movement of the eastern block of this fault was down and southward in the Jackson Bangor No. 6 opening, it is altogether probable that the appearance of a gentle syncline in the strata on the east side

of the United States quarry is due to the dropping of the upper limb of a syncline below the erosion surface at this point. Quarrymen commonly speak of a fault in this quarry and it is believed that this is the fault referred to.

The cleavage strikes uniformly about N. 70-75° E., and dips 40-50° SE. Grain trends N. 47° W.

Because of the inaccessibility of the walls, the joints in this quarry were not studied in detail. Those recorded strike N. 30° E. with dips of 80° NW., or N. 20° W., dipping 58° N.

History and development.—This is one of the oldest quarries of the district. It was originally a part of the estate of J. I. Blair, the former part owner of the Bangor & Portland Railroad. It was apparently operated under lease by the United States Slate Company, in which J. Masters and Barney Ribble were the principal stockholders. In 1907 the property was purchased by the Jackson Bangor Slate Company. Of recent years it has not been worked, the period of cessation beginning with the recent great war, but the quarry is now again being opened on the western side.

Two masts and the remains of an old power plant are still to be seen on the dump to the south. Here are also seven shanties.

32. HERCULES QUARRY.

Location and dimensions.—This opening is only 100 feet north of the United States quarry. It measures 400 by 200 feet, the longer dimension extending northeastward. It is worked on one level only, the bottom of the quarry; this has a depth of 235 feet below the surface. The dump lies to the east.

Various names have been applied to this opening, including Masters, Bolger, and Jackson Bangor No. 2 quarry. The old name Hercules quarry is here retained.

Geology.—The beds exposed in this opening make up the Pennsylvania "run," a series that derives its name from the quarry to the east. As far as known, these strata are not seen in other quarries of the region. One conspicuous bed, having a thickness of 11 feet, 3 inches, is seen in the present working level near the north wall; the other beds in this level are all thinner.

At the surface the beds strike N.47°E., and dip northward 31° along the north wall of the quarry and 39° on the south wall. At a depth of 80 feet they assume a vertical position, which marks the almost horizontal axis of the northward overturned anticline. There are several smaller rolls, to a depth of about 150 feet; then the beds resume the northward dip, which they retain to the bottom of the quarry. There is evidence in the lowest part of the wall, however, that the beds again assume a steeper dip, suggesting the occurrence of another axis with depth (see Figure 37).

Several smaller faults are visible in the northwest wall, the bedding traces being offset as they cross the fault planes. In the bottom of the opening there is a small fault, the strike and dip of which are N. 5-20° W., 38-50° NE., respectively. The displacement is about 7 feet in a N. 50° W. direction along the fault plane. Striae on the fault wall dip 25° SE. in the plane of the fault: the movement was

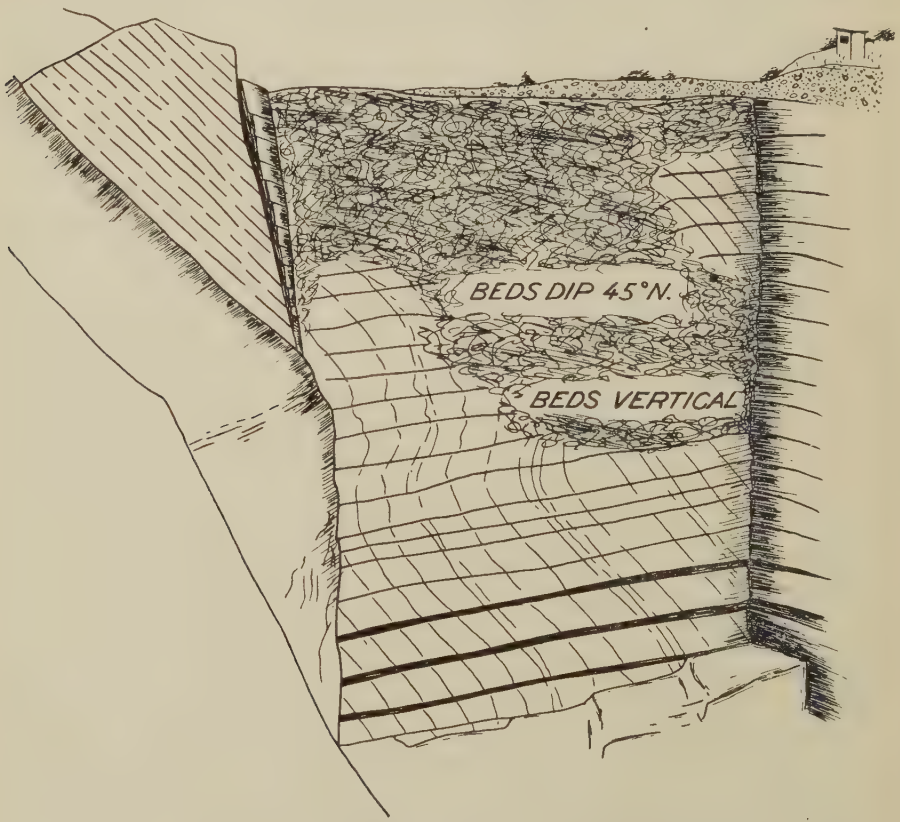


Figure 37. Southwest wall of Hercules quarry, from east corner. Anticlinal axes at depth of 80 and 200 feet. Some foreshortening in deeper parts of quarry.

thus largely horizontal, the east side moving northward. This probably represents a minor adjustment of a thrust nature, giving the same effect as the faults already mentioned in the Albion Vein and the Jackson Bangor No. 7 quarries, and yet to be described in the Jackson Bangor No. 6 quarry (see below). Projected to the surface, the fault plane appears to coincide most closely with the fault of the Jackson Bangor No. 6, but as the movements in these two faults are oppositely directed, it is difficult to correlate the two. The Hercules fault is of too small a displacement to be shown on the maps.

Cleavage strikes N. 43° E., and dips 24° SE. at the surface. On the working level the strike is N. 65-90° E., and the dips are slightly lower. Grain trends N. 50-60° W. The joints measured all fall into a N. 60° E. system, much like one of the sets observed in the Albion Vein and Jackson Bangor No. 6 quarries (see Plate XVII, C).

History and development.—This quarry was opened about 1885 and long worked by the Hercules Slate Company, whose president was William Masters, under a lease obtained from J. I. Blair and later from the Jackson Bangor Slate Company. The company was incorporated in 1905. At this time the opening was spoken of as the Masters quarry. In 1920 the lease and operations came into the hands of the Belmont Slate Company, the chief stockholder being Mr. Thomas Bolger of Bangor. The present capitalization of the Belmont Slate Company is $50,000.

The mill is equipped with 3 sawing tables, 2 planers, 1 rubbing bed, and 1 buffing machine.

Five shanties were in use in 1923.

The products include roofing slate, blackboards, slate for plumbing fixtures, grave vaults, table tops, and other structural material, and electrical slate.

33. PENNSYLVANIA QUARRY.

Location and dimensions.—In ground plan this is a rhombic opening lying about 1,200 feet N. 70° E. from the Pen Argyl postoffice and about 500 feet N. 30° E. from the Hercules quarry. As the opening has long been abandoned and is surrounded by a dump, it is not readily seen from the street. It measures 300 feet along each side.

Even as early as in 1883 the quarry was "full of water."[113] Today the opening shows about 30 feet of slate above the level of the water. The probable total depth is 150 feet.

Geology.—The slate comes to the surface without overburden.

The beds opened are probably slightly higher in the sequence than those in the Hercules quarry. They were nowhere actually measured, but one conspicuous bed, estimated to be 10 feet in thickness, occurs about midway in the northwest wall. The beds strike N. 55° E., and dip 62°N. at the northwest edge, 22°N. at the southeast edge. North of this quarry, therefore, an anticline axis should emerge.

Cleavage strikes N. 62° E., dips 22° S.; grain strikes N. 55° W. and is vertical.

History and development.—The quarry is on what was formerly the property of J. I. Blair, but is now owned by the Jackson Bangor Slate Company. It was bought from the Blair estate in 1907 and has experienced repeated revivals of operation but apparently none of long duration. It was the first quarry opened in the Jackson Bangor

[113] Sanders, R. H., Geology of Lehigh and Northampton Counties: Pennsylvania Second Geol. Survey, D. 3, vol, I, p. 97, 1883.

properties, and is therefore sometimes spoken of as the Jackson Bangor No. 1 quarry.

No quarry equipment remains in place.

The products were roofing slate, blackboard material, and structural slate.

34. DIAMOND QUARRY.

Location and dimensions.—This quarry lies about 200 feet south of the middle of the United States quarry. It is a roughly rhombic opening, measuring about 300 feet in each direction, although the southwestern side is shorter than the other. The depth of the slate exposed is 75 feet from surface to water level, but probably the quarry is at least 100 feet deeper, to judge by the slate dump to the south.

Geology.—There is here no glacial overburden, only weathered slate being seen above rock fresh enough to be quarried.

The beds exposed constitute the Diamond "run" and are seen again in the Parsons and New Diamond quarries. In the Diamond quarry they were not studied in detail because not accessible.

The structure is uniform, as far as can be seen, everywhere in the quarry; thus the strike and dip of three observations taken, respectively, in the northeast wall, the south wall, and the extreme southeast corner are (1) N. 65° E., dip 69° SE., (2) N. 65° E., dip 73° SE., (3) N. 72° E., dip 65° SE.

The cleavage strike varies greatly, but apparently the mean is about N. 40°E., with gentle south dips. The grain trends N.53-63°W.

The northwest ("back") wall is developed along a "loose ribbon." This bears numerous joints two feet or less apart and appearing to strike N. 15-35° E., and to dip 50° S.; these are quartz- and calcite-filled. In the southeast corner several joints strike N. 5° W., and dip 50° SW.

It is said that the water level of this quarry is related to that of the Jackson Bangor No. 5 (see below). When No. 5 is drained, the level in the Diamond quarry is noticeably low.

History and development.—Like the Pennsylvania quarry, this opening has been abandoned for several years.

It, too, passed from the hands of J. I. Blair into the ownership of the Jackson Bangor Slate Company. The opening was operated by Camm, Sandt, and Kellow, under the name of the Diamond quarry, a lease having been arranged with the owners.

There is no machinery on the dump, and of the buildings only one small transformer station remains.

35. JACKSON BANGOR NO. 6 QUARRY.

Location and dimensions.—This deep opening lies about 1,200 feet S. 50° E. from the Pen Argyl post office, and is the next quarry due east of the Jackson Bangor No. 7 opening. At the surface it is

roughly rhombic in form, the sides measuring 250 and 300 feet, the dimensions in the northeast direction being the greater. The depth was 380 feet at the deepest part of the lowest level (1924), but continued sinking since has probably increased that figure. In addition to this lowest working level, which rises northward with the cleavage, there are two higher "pieces" at a depth of 290 and 145 feet below the surface. These upper levels rise as benches along the northeast side of the quarry; the more northerly bench is the highest "piece" or level.

The large dump to the south has received all the material removed from the opening.

Geology.—This quarry on its several working levels opens all of the Albion "run." On the southern edge of the lowest level is the Hard Front big bed. On the uppermost level the lower part of the Jenny Weeks bed is seen against the north wall. The several beds have been described in various places in this report and their order is given in the section entitled "The Economic Geology of the Slate."

Structurally the quarry exposes a rather open syncline with an almost flat axial plane, the two upper levels being in the upper (southern) limb and the lowest piece in the northern limb. Thus, on the topmost level the beds strike N. 60-65° E., and dip 65-80° S., while in the lowest level they strike N. 40-50° E., and dip 10-35° NW. The strikes on the upper and lower limbs diverge, as noted, and the cleavage strike is more nearly parallel with the strike of the beds below than above. There is a suggestion in these relations that the axial line of the beds swings northward as it is followed east.

The cleavage dips gently south, 15-30° and strikes N. 40-60° E. Grain trends N. 45° W. For jointing, see Plate XVII, B, p. 132.

Three faults are seen in this quarry. They all strike northwestward and dip to the northeast, and there is evidence that the movement is mainly horizontal and southward on the east side of the fault plane. One is seen in two of the quarry walls near the eastern corner of the opening, about 50 feet below the surface. The other two are on the lowest working level. For a further description of these faults, the reader is referred to pages 63-65 in the section describing the structure of the slate. Offsets of a similar nature, but on a much smaller scale, are visible on the northwest and southeast walls.

Beginning at the surface, along the northeast wall of the quarry, a conspicuous "loose ribbon" leads downward in a curve parallel with the bedding. Although there apparently has not been much movement along the plane at this point, it is believed that the open crevice or "loose ribbon" represents the trace of a bedding slip fault.

In quarrying, the management has found operations very expensive in certain stages in the descent, because of numerous closely spaced joints attributed to the three high angle faults mentioned. Although

it is true that some jointing is associated with these faults, it is almost certain that by far the greater portion of the observed joints are related to the movement along the bedding slip fault, a structure which, being almost parallel with the bedding, is readily overlooked. On the whole, it is probable that this quarry will be more, rather than less profitable as depth is gained, as this increase in depth gives to the working level a greater horizontal distance from the bedding slip, the latter receding farther and farther into the wall.

History and development.—This opening was worked by the Jackson Slate Company previous to its purchase in 1907 by the Jackson Bangor Company.

It is served by a mill in common with the Jackson Bangor No. 7 and No. 5 quarries. The mill equipment is described under the detailed account of the Jackson Bangor No. 5 quarry.

The landing for the No. 6 quarry is on the dump to the south.

36. JACKSON BANGOR NO. 6 SMALL QUARRY.

Location and dimensions.—This small opening lies immedately southeast of the main opening of the Jackson Bangor No. 6. It is about 75 feet square and 105 feet deep.

Geology.—In the northeast corner of the opening the Gray bed is exposed. The structure resembles that of the main opening. At the surface the strata dip 48° SE., but in the bottom the dip is 75° SE., and is plainly steepening. The extent of the horizontal shift involved in the fault described as visible in the southeast corner of the No. 6 quarry is indicated by the southward shift of the Gray bed from its outcrop at the middle of the main No. 6 quarry to the northeast corner of this small opening, a displacement, as measured along the horizontal reference surface, of about 125 feet.

History and development.—This quarry is now used as a dump site only. Its history is the same as that of the No. 6 main opening.

37. JACKSON BANGOR NO. 5 (VALLEY) QUARRY.

Location and dimensions.—This quarry is about 400 feet N. 10° W. of the town of Delabole, on the Bangor & Portland (Delaware Lackawanna, & Western) R. R., and about 100 feet east of the small quarry just described. It is one of the larger openings of the Pen Argyl group, measuring 500 feet N. 80° E. by 250 feet N. 30° W.

Development is in three levels, a main or bottom "piece," which occupies most of the opening, and two small rhombic steps in the northeasterly corner of the quarry that are each about 110 by 125 feet in size. The upper level has a depth of 95 feet; the intermediate one is 140 feet deep; the main or bottom "piece" varies in depth from 180 to 255 feet.

An extensive dump lies south of the quarry.

Geology.—There is a heavy overburden of 30 feet of rounded, unstriated boulders, set in sandy clay. This cover thins westward and is best seen on the east wall.

Beneath this, near the middle of the northeast wall, the Gray bed is plainly seen and shows again in the bottom of the quarry. The entire Albion "run" is thus exposed in the workings, although the divergence between the strike of the beds and the longer dimension of the opening carries the Gray and lower beds into the southeast wall.

The structure is that of a northward overturned anticline above and its complementary syncline below: the beds at the surface dip 44° NW.; but lower down they dip southeastward at moderate angles; on the working level the dip is northward again, from 50 to 80°. The strikes vary slightly, but the average is about N. 70° E. Cleavage strikes N. 80° E., and dips 15-30° S. Grain trends N. 45-53° W.

It is difficult to speak of any of the joints as falling into distinct systems; almost all strike northeastward, and of these many strike N. 50° E., whereas another group strikes about due east; both have vertical dips. For the joint pattern, see Plate XVII, A, p. 132.

Near the northeast corner a fault is visible on the wall. The trace of the fault plane dips northward, which suggests a northwest strike with a northeast dip, thus similar to the faults already described in the quarries to the west. Unfortunately, however, the fault plane was not accessible and its actual strike and dip, as well as the amount of movement, could not be measured. The beds east of the fault, however, are said to have moved north. Small faults with similar movement are seen near the surface in the northeast wall just north of the east corner.

History and development.—This quarry, together with the Jackson Bangor Nos. 7 and 6, is being worked at present by the Jackson Bangor Slate Company. It was originally a part of the Blair estate, and operated under lease by the Valley Slate Company, Wm. Harding, manager. In 1907 the property was purchased by the Jackson Bangor Slate Company. In 1908, the No. 6 and the No. 7 quarries produced together 75,000 squares of roofing slate, but production declined greatly during the war and has but lately resumed normal size.

The company is undercapitalized, its stock being valued at $500,000.

A very well equipped mill serves all three quarries. It has been described by Bowles[114]. The landings are on the south side of the three main openings, so that the tracks leading to the mill are accessible from the quarries. A large stock pile lies north of the mill.*

The production includes roofing slate, blackboards, electrical slate,

[114] Bowles, Oliver, Op. cit., p. 79, fig. 28, 1922.

* A recent innovation is an excellently equipped roofing slate mill; for a description see Bowles, Oliver, Recent Progress in Slate Technology: U. S. Bur. of Mines, Reports of investigations, fig. 1, 1926.

and slate for structural purposes. The company makes a specialty of the latter material shaped to meet particular needs.

38. QUARRY.

Location and dimensions.—About 600 feet due east of the Jackson Bangor No. 5 quarry and east of the road leading from Pen Argyl to Delabole is an old pit, long deserted. It measures about 100 by 200 feet, the longer dimension extending N. 30° W.; the opposite sides are parallel. The pit is only 20 feet deep, hence does not reach water level. Some waste slate is dumped at the edges of the opening but most of what was removed was overburden, and apparently has been utilized as road metal.

Geology.—The slate here is covered with 10 feet of reddish glacial clay and rounded boulders, unassorted.

The strata could not be correlated with any of the measured sections, but are said to be well below the Albion "run."

The beds strike N. 75° E., and dip 16° S. The cleavage strikes N. 58° E., dipping 3-5° N. The strata are here apparently on the south (upper) limb of a syncline with horizontal axial plane. The grain trends N. 35° W.

History and development.—Nothing of the history of this opening could be learned, other than that quarrying was done more than 10 years ago and was abandoned when it was found to enter beds below the Albion "run."

No machinery is seen and it is thought that the work scarcely passed the stage of stripping.

Several small trenches are opened at the southern side of the main opening.

39. QUARRY.

Location and dimensions.—Another old pit lies about 1,800 feet N. 80° E. from the Diamond quarry and 100 feet north of the road from Pen Argyl to the American Bangor opening. The pit is now filled with water, and so overgrown with grass as to be difficult to find. It is small, measuring only about 130 by 75 feet.

Geology.—There is no glacial overburden here; the slate has decayed to a depth of about 5 feet.

The beds are said to be of the Albion "run." They strike N. 62° E., and dip 23° S. The dip thus resembles in direction that in the last described quarry (Quarry No. 38), but is steeper, probably because the axial plane of the fold dips southward.

In the northwest corner the cleavage strikes N. 25° E., and dips 8° N. at the one locality where the strike was observed. Grain trend is N. 40° W.

History and development.—The history is not known. No equipment remains.

40. OLD CROWN QUARRY.

Location and dimensions.—This quarry lies about 1,500 feet N. 60° E. from the Pennsylvania quarry and is only about 50 feet north of the Pen Argyl-Bangor highway. It measures 140 feet N. 38° W., and 115 feet N. 57° E., the longer dimension being parallel with the grain. The opening is 20 feet deep to water level, but must have a far greater total depth. A large dump is located north of the quarry.

Geology.—The upper ten feet are a sand and gravel overburden, of glacial origin. Immediately beneath this is fresh slate.

Projecting the strike, the beds should here be the same as at the Pennsylvania quarry to the west. The strike is N. 60° E., with dips 25° W. One bed measures 9 feet along the cleavage. The cleavage strikes approximately N. 58° E., and dips gently southward. Grain trends N. 40° W.

History and development.—No machinery remains on the dump. The history is given under the description of the Crown quarry.

41. CROWN QUARRY.

Location and dimensions.—About 1,800 feet N. 50° E. of the Pen Argyl city park, and in the little settlement of West Bangor is the new Crown quarry, a rectangular opening measuring 300 by 225 feet, with its larger dimension extending about due northwest. Some 60 feet of slate are visible in the wall above water level, and the opening was probably about 50 feet deeper. A large dump is situated to the south of the quarry.

Geology.—Under a glacial overburden, from 3 to 10 feet thick and resembling that in the West Bangor and Bangor Fidelity quarries, the beds of slate appear striking N. 53° E., with a dip of 72° N. at the south end of the quarry, but only 33° at the north end. A synclinal axial plane with a southward dip may be expected to appear at the surface south of this quarry.

The beds exposed are continuous along their strike with those in the West Bangor quarry, which is described on a later page.

Cleavage strikes N. 53° E., dips 40° S. The grain trends about N. 40° W. On account of the heavy weathering of the slate, joints are not readily studied from the surface. A bedding slip fault, unquestionably continuous with that seen in the Bangor Fidelity and West Bangor quarries, shows in the northeast quarry wall about 100 feet from the south end, but the slipping described in the easterly quarries is greatly reduced, and it is evident that the faulting is on the wane westward (compare with p. 223).

History and development.—Quarrying here was begun by the firm

of Alfred Doney & Brothers in 1892. In 1910 this and the Old Crown quarry to the south came under the management of the Crown Slate Company of Pen Argyl, Pa. The main stockholders were Mr. J. S. Morss of Pen Argyl, and Mr. Fred Hussey of New York City. Capital stock for $50,000 was issued.

An old mill and power plant are still on the dump south of the opening. Three cables stretch across the quarry from the southeast side.

The production included mainly electrical, structural, and blackboard material. Very little roofing slate was made.

42. BANGOR FIDELITY QUARRY.

Location and dimensions.—About 600 feet east of the Crown quarry is the western of two almost equidimensional openings. Both are rhombic in plan and are about 500 feet long in a N. 55° W. direction and 225 feet wide. The eastern is the West Bangor, the western the Bangor Fidelity quarry.

The Bangor Fidelity is about 300 feet deep at its greatest depth. It is opened on one level only, which inclines steeply (24°) southward, parallel with the cleavage.

The large dump is south of the opening and merges eastward with that of the West Bangor.

Geology.—This quarry is so close to the West Bangor that the geology of the two openings is practically identical. There is an overburden, 8 feet thick, of glacial material. Beneath this the slate surface, rising southward, shows beds striking N. 58° E., dipping 35° NW. at the northern end of the quarry; at the south, the beds strike similarly, but dip 85° S.

The cleavage strikes N. 53° E., dips 40° S.

The beds exposed are the same as those in the West Bangor opening.

History and development.—History and development of these openings are linked with those of the West Bangor quarry and are discussed under that head. The mill and factory equipment serve both openings.

43. WEST BANGOR QUARRY.

Location and dimensions.—A wall, in places only two feet thick, separates this from the quarry to the west. The dimensions are similar to those of the Bangor Fidelity opening. The quarry is worked on one level which inclines about 25° south. The large dump lies south of the opening.

Geology.—The slate is covered by a glacial overburden about five feet thick. This consists of sandy clay, largely orange in color, in which are rounded boulders.

Beneath this the slate comes to view, first weathered, then fresh. The beds worked include four conspicuously thick ones. Thickness

measurements made in the quarry are as follows, in the order of superposition:

Measured sequence in West Bangor quarry.

Name	Thickness Ft.	Thickness In.	Chief use
Big bed	3	6	electrical slate
Hard roll		6	
Intervening beds with "ribbons"	90	0*	
Big bed	8	2	blackboard
Hard roll		3	
Intervening beds with "ribbons"	10	6*	
Big bed	6	10	various
Hard roll		4	
Intervening beds with "ribbons"	90	0*	
Big bed	4	5	blackboard
Hard roll		23	

*Thickness estimated, not accurate.

The slate is somewhat softer and more brittle than that in the Albion "run."

At the surface in the northern end of the quarry the beds strike N. 57° E., dip 43° N.; in the southern end the dip is 65° S. In the quarry wall the dip reverses and in the working level all beds dip north, at angles of 10 to 15°. As in the Bangor Fidelity quarry, therefore, a synclinal axial plane, dipping 14° S., emerges near the middle of the quarry, and an anticlinal axial plane is doubtless present a little south of the opening.

The cleavage at the surface strikes N. 61° E., dips 30° S. In the bottom its strike and dip are unchanged. The grain trends N. 45° W., dips 80° E.

In the wall of the quarry a set of joints trending N. 55° E., and dipping 75° S. is seen. In the bottom a system strikes N. 10-30° E., dips 70° S. There is a tendency for the dips of the first set of joints to cut the bedding dip at right angles.

About midway in the quarry sides a bedding slip fault comes to the surface. With it are associated the usual numerous joints gently inclined to the plane of the fault. The beds south of the fault bulge and dip noticeably first south, then north, while those north of the fault are vertical near the plane and dip north farther away; the closer compression of the fold south of the fault plane is thus clearly defined. This bedding slip fault can be traced westward through the Bangor Fidelty and Crown quarries; its outcrop at the surface is marked by a shattered zone that weathers so easily as to leave a

conspicuous notch in the quarry wall. The feature is shown in Plate XXX, B, p. 209.

History and development.—The owner of the property on which this and the Bangor Fidelity quarry are located is the firm of Solomon Flory and Company. The West Bangor quarry was opened in 1887 by John Hull of Scranton. After this, its operation was taken over successively by a firm represented by a Mr. Winsborough, by the Lehigh Coal & Navigation Company, and by Kress & Speer of Pen Argyl. In 1910 operations ceased, but shortly after the Bangor Slate Mining Company resumed quarrying; this firm failed in 1919.

The present operator is the Bangor Fidelity Slate Company, in which the main stockholders are Messrs. Oliver Labar, J. I. Weiss, J. Hamm, Jr., A. H. Hamm, and Dr. Dilliard of East Bangor.

Two "factories" are located on the dump. Of these the western is a large shed equipped with two buck-saws, a rip-saw, four planers, two rubbing beds, an emery wheel for sharpening knives, a vertical carborundum wheel, propelled at 1,600 revolutions per minute, for sawing and bevelling, and a Vermont type buffer. Transportation from table to table is effected by a boom and tackle, and tracks lead through the mill. Two heavy saws are mounted outside the factory, and here there is also another boom.

East of this is a smaller mill, containing buck-saw, planer, rip-saw, carborundum wheel (for sawing), and rubbing bed in series. This mill is used mainly for finishing electrical slate.

A small wood shed, with a saw, is provided for crating finished products.

The tracks that lead through these mills turn east after their exit from the buildings, lead past both quarries, and run along a line of seven roofing shanties. It is thus possible to load roofing material on hand cars in the mill and transfer it to the shanties, or to place blocks destined for the shanties on the cars directly under the masts. A further continuation of these tracks will permit the final transfer of finished roofing slate to the stock house.

Three masts serve this quarry, and another three support cables for the Bangor Fidelity opening.

The products are structural, electrical, roofing, and blackboard slate.

44. BANGOR SUPERIOR QUARRY, SMALL OPENING.

A small opening of the Bangor Superior quarry lies just west of the main hole bearing that name. It represents a stripped area practically continuous with the main hole.

The geology, history, and development of this quarry are so closely similar to those of the larger Bangor Superior quarry that they are not separately discussed.

45. BANGOR SUPERIOR QUARRY.

Location and dimensions.—The Bangor Superior quarry is about half a mile due west of Roseto, and about 2,000 feet N. 45° E. of the West Bangor quarry. It is an almost rectangular opening, roughly 200 feet square. The depth to the present water level is 130 feet.

Work is progressing on a series of irregular levels along the southwest side of the opening, beginning at the surface.

The dump lies northeast of the quarry.

Geology.—In the quarry walls the glacial overburden consists of faceted quartzite and conglomerate boulders and slate chips in a sandy clay matrix. The thickness is as much as 10 feet locally.

Three thick beds are worked, one of which is the Johnny Kress bed, having a "length" of 9 feet, 7 inches along the cleavage; this bed, by careful measuremenets, could be correlated with one of the thick beds in the West Bangor quarry. Stratigraphically about 40 feet beneath it is a bed about 7 feet "long" (measured on the cleavage); roughly 20 feet lower in the sequence is another thick bed about 10 feet "long."

A feature in this quarry is the northwest strike of the beds. Thus, at the surface the strike and dip are N. 62° W., 11° S. In the bottom of the quarry along the south side the strike is N. 76° W., the dip 12° S. The strike of the cleavage, however, retains a northeastern direction, being N. 61° E., with a 35° S. dip at the surface, while in the bottom the relations are the same. It is thus clear that the quarry is on a westward pitching syncline.

The grain generally trends N. 50° W., dips 75-90° E.

A set of joints, striking N. 42-50° W., and dipping 60-80° S., is seen in the east corner of the opening.

History and development.—This quarry was first opened in 1884 by a Mr. Gumm. The lease on the property passed into the hands of the following at the times indicated: Solomon Flory, 1886; Schoch and Messinger, 1890; Wm. H. Keenan, 1895; Thomas Bolger, 1897; David Stoddard, 1899.

In 1901 Harry A. Mackey bought the property outright. Then the quarry, machinery, and land were purchased successively by the following: Bangor Star Slate Co., 1905; Slate Products Co. of America, 1906; Bangor Royal Slate Co., 1909; Slate Products Co., 1920.

Since 1920 the quarry has been continuously operated by the Slate Products Company, Incorporated, of Bangor, Pa. Bonds issued and outstanding amount to $20,000, stocks to $21,600. The chief stockholders are Messrs. David Burke, E. V. Gillner, and N. H. Hazen.

The mill is on the dump east of the opening. The equipment includes two buck-saws, four rip-saws, three planers, two rubbing beds, and a Vermont type buffer. The rubbing beds are so belted to the drive shaft as to be stopped separately.

The dumping arrangement permits the piling up of waste slate in two places, one to the east, the other northwest of the opening. Cableways are used in both cases, and gravity returns the cars after unloading.

Three cables and masts serve the opening.

The products include structural and electrical slate and smaller quantities of roofing slate and blackboards.

46. KELLER QUARRY.

Location and dimensions.—This small opening is on the northerly slope of the same hill as the American Bangor quarry, and about 1,200 feet due north of that quarry. The hole is small and only a little slate is seen.

Geology.—No overburden is present. The slate strikes N. 30° E., dips 60° S. Cleavage is horizontal or dips gently northward, with a slight tendency to curve. No beds exceeding two feet in thickness are exposed. The strata are said to have been a part of the North Bangor No. 3 "run."

History and development.—This small opening was little more than a prospect. It and the other small opening 400 feet south were made by Oliver Saeger and Benjamin Austin.

47. STECKER QUARRY.

Location and dimensions.—The Stecker quarry is a prospect pit, about 35 by 140 feet in ground dimensions, lying 800 feet due north of the northern corner of the American Bangor quarry. The longer dimension extends northeast, at right angles to the grain. About 12 feet of slate are seen on the southeast side.

Geology.—Under two feet of overburden slate shows, the bedding striking N. 31° E., dipping 63° S. on the northwest side, but only 33° S. on the southeast. Many hard rolls are visible. The opening is thought to have exposed the North Bangor No. 2 "run."

The grain trends N. 40° W.; cleavage is horizontal.

History and development.—For the history of this opening the reader is referred to that of the Keller quarry above.

48. UHLER QUARRY.

Location and dimensions.—The road from Delabole to Bangor passes about 1,000 feet south of the Bangor Southern and American Bangor quarries and then, continuing eastward, crosses one of the head waters of Martins Creek before rising to the hills southwest of Bangor. Up the valley of the creek mentioned and on its west side, approximately 600 feet north of the road, is a small opening (Quarry No. 49) on the

property of Mr. Uhler of Bangor. It measures 20 by 40 feet and is 15 feet deep to water.

About 400 feet farther north, on the same side of the stream is another small quarry, here spoken of as one of the Uhler quarries and given the quarry location No. 48. This latter opening is about 40 feet square and probably 40 feet deep, but filled with water so that now a depth of only 10 feet of the walls are seen.

Geology.—The beds exposed in the north opening are said to be in the North Bangor or North Bangor No. 3 "run," but they could not be identified in these studies. They strike N. 70° W., dip 15° N. Cleavage strikes N. 80° E., dips gently south. The cleavage is fair, but the slate is rather closely ribboned.

History and development.—This and the opening 400 feet south of it are said to be on the Uhler property. They were opened between the years 1904 and 1910.

49. UHLER QUARRY.

The location and dimensions and the history of this opening have already been given under the description of Quarry No. 48.

Geology.—The excavation is said to have laid bare a part of the Old Bangor "run." The beds strike due east, dip about 35° N. Those exposed are rather closely ribboned, and overturning is suggested in the northeast corner. It is reported that there was a big fault in this opening, but the rumors are vague and the type of movement cannot be defined.

Development.—An old boiler and one or two wooden sheds remain on the property.

50. AMERICAN BANGOR QUARRY.

Location and dimensions.—This opening is about midway between the towns of Bangor, Pen Argyl, and Ackermanville, and 1.5 miles from each. Its high dump, on which one mast stands, like a flag staff above a ruined fort, is visible from high points several miles distant. The large opening is about 300 feet wide and 500 feet long, with a rectangular wing extending yet farther into the southeast side. The greatest length is in a northeast direction. The maximum depth to the water that fills the quarry bottom is estimated at 270 feet, but the total depth is reported to have been about 370 feet.

The large dump extends virtually all around the quarry, but has mostly been built up on the eastern sides.

Geology.—The thickness of the overburden here is 15 feet, maximum, and consists of decayed slate. Beneath this the beds are seen to strike N. 60-70° E., dip 15-30° S., the steeper dips being along the south side. It is said by Mr. Blake of Bangor that the strata steepen slightly in the bottom of the quarry. Apparently the beds are on the upper

limb of an overturned syncline having a southward dipping axial plane. The structure probably pitches west, so as to carry it below ground level in the Bangor Southern quarry.

The actual correlation of these beds in the standard scale was not possible because the quarry walls are inaccessible, but operations are said to have exposed the middle of the Old Bangor "run" and the Gray bed was encountered at no great depth.

The cleavage strikes approximately N. 70° E., dips 8° S. The grain trends N. 43° W., and is vertical.

Vertical joints are prominently developed, striking N. 48-53° E. Such a joint, apparently continuous, forms the entire northwest quarry wall. The surfaces of joints of this system are commonly quartz- or calcite-coated. The quartz is clearly the earlier mineral.

Structurally the beds in this quarry, as far as can be determined, are continuous with those in the southern of the two Uhler quarries to the east. The relation is also shown in Figure 38; here the westward

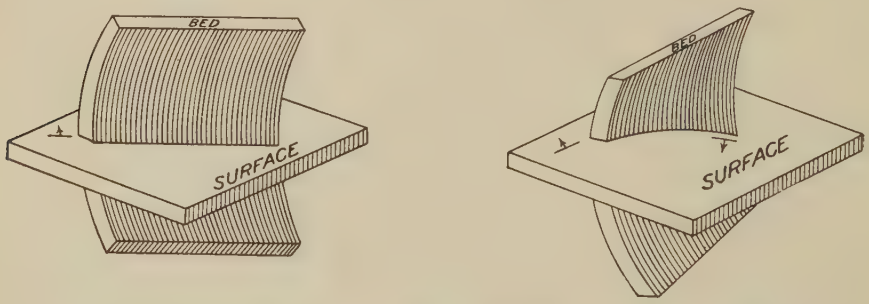


Figure 38. Fold with horizontal or gently dipping axial plane; to show effect of pitch on line of outcrop and direction of dip.

pitch of the structure makes the beds at the surface dip north toward the west (as in the Bangor Southern) and south toward the east (as in the American Bangor quarry); compare with p. 229.

History and development.—Quarrying was begun here in 1875 by General Frank Reeder of Easton. After repeated changes in the ownership of the property, Mr. E. J. Long of Bangor and General Reeder sold out to Mr. R. S. Brown of Easton. In 1914 the company headed by Mr. Brown failed, apparently not because of the lack of good slate, but because of the reduced market incidental to the beginning of the World War.

An old factory, dismantled, stands east of the opening. Other buildings are a boiler house, hoist houses for the 5 hoists on the northeast side, 12 roofing shanties on the northeast, and 11 on the southeast side of the hole. The quarry was crossed by 4 cables operated from the southeast and 5 from the northeast side. Two "motion shanties" overhang the opening.

The production included roofing slate, blackboards and structural material.

51. BANGOR SOUTHERN QUARRY.

Location and dimensions.—This opening is N. 30° W. about 1.5 miles from Ackermanville. It is west of the highway from Ackermanville to Pen Argyl. It measures 300 feet by 150 feet, the larger dimension extending northwestward. Approximately 20 feet of walls are exposed to water level, of which 15 feet at most are glacial overburden. A dump and some old machinery lie south of the opening.

Geology.—The glacial overburden consists of numerous boulders, many of red Catskill sandstone, and generally faceted or subangular. These are set in a matrix of sandy clay.

Beneath the overburden the slate is seen striking N. 57° E.; at the northern end of the opening the dip is 31° NW., but decreases southward to 20°. The cleavage strikes N. 65° E., dips 20° SE. Grain trends N. 43° W., and dips vertically. No jointing is seen.

It is said that at a depth of 180 feet the beds reverse so as to dip southward below the water level. This might be expected if the dip at the American Bangor is considered. The beds worked were mainly in the Old Bangor "run."

History and development.—This quarry was opened in 1890 by a company consisting of E. J. Johnson and F. W. Duncan. It was shut down again in 1895. In 1900 operations were resumed by James Masters, and shortly after the property was sold to the American Slate Company. In 1904-5 slate was removed under a lease from the American Slate Company. Then quarrying was abandoned and never resumed.

The equipment remaining consists of two pulleys, cables, and masts.

52. REICHARD QUARRY.

Location and dimensions.—About 400 feet N. 57° E. from Quarry No. 53 is a small pit measuring 70 feet long by 30 feet wide, the greater length being northwestward. The depth is 18 feet.

Geology.—Beneath an overburden of weathered slate, thin beds of sandy slate are exposed striking N. 46° E. and dipping 43° SE. The cleavage strikes N. 70-80° E., and dips 20° S.

History and development.—This and the pit to the southwest were opened as prospects by Dr. Reichard of Bangor and Mr. Speer of Delabole.

53. REICHARD QUARRY.

Location and dimensions.—This opening lies N. 60° W., about 1,200 feet from the Bangor Southern, on the north slope of a small hill. It is about 100 feet long, N. 45° W., by 40 feet wide, and roughly rectangular; the depth is 30 feet to the top of the rubbish which now

partly fills the hole, but may once have been greater. A small dump is built up near the quarry.

Geology.—In the wall the beds are seen to turn, dipping 68° N. at the south end and surface, whereas the strike and dip in the north end at the surface are N. 50° E., 68° S. Below the surface the dip is everywhere south. Near the south end, therefore, an anticlinal axial plane, dipping southward, emerges.

The strata could not be definitely correlated with those of other quarries, but are presumably in the upper part of the Bangor beds.

Cleavage strikes about N. 45° E., dips 11° S. Grain trends N. 47° E.

History and development.—This and another small hole described above (Number 52, Quarry Location Map) were opened by a Dr. Reichard of Bangor and Mr. Milton Speer of Delabole.

Nearby openings.—Several smaller openings are seen on the west slope of the hill on the north side of which this quarry lies. None are more than 5 feet deep and none show bedding.

54. DELABOLE QUARRY.

Location and dimensions.—The old Delabole quarry is located about 1,200 feet N. 25° E. from the station of Delabole on the Bangor and Portland (Delaware, Lackawanna & Western) Railroad. It is a rectangular opening, 250 feet long and 100 feet wide, the greatest length extending northwestward. The slate and overburden exposed above the water level are about 20 feet, but the depth was probably at least 80 feet greater. The dump lies to the west.

Geology.—The overburden shows 8 feet of peculiarly brick-red glacial clay, set with subangular and faceted boulders, none of which give evidence of much water wear; the red color appears to be due to the presence of much ground-up red Catskill sandstone.

Beneath this overburden are about 5 feet of decayed slate. The rest of the depth to water level shows beds striking N. 50° E., and dipping 62° N. at the north end of the opening, vertically at the south. The cleavage strikes approximately parallel with the beds, dips 12° S. It is believed that these bedding-cleavage relationships suggest that the quarry is south of a southward dipping synclinal axial plane, but it is at least possible that it is located just above a northward recumbent anticline instead, the great thickening of the beds accounting for the vertical dip to the south. The beds are still vertical at the greatest depth worked.

The strata exposed are not very thick. No single bed exceeds two feet. Some blocks on the dump show cleavage faces five feet "long." The beds opened were in the Grand Central and Old Bangor "runs." The grain trends N. 47° W.

History and development.—This quarry was opened in 1900 by Mr. William Blake of Bangor, capitalized by a company consisting of E. J.

Johnson, James Masters, and Mr. Blake, and later including a Mr. Turner of Philadelphia.

In 1903-4 the property was purchased by the American Slate Company. Later it was leased by a company and worked under the direction of Mr. Cotton Amy, who exposed the Gray bed of the Bangor "run." In 1910 work was stopped and has not since been resumed.

An old boiler house is situated 300 feet away, east of the road.

The production is said to have been mainly roofing slate.

55. QUARRY.

Location and dimensions.—About 300 feet north of where a road leads west from the Delabole-Pen Argyl highway that runs up the valley of Waltz Creek, and about 3,000 feet south of the Jackson Bangor No. 5 (Valley) quarry is a cut just east of the highway. This measures about 50 feet square and is 40 feet deep.

Geology.—Judging by the strike, the beds here must be about the same as in the Delabole quarry (see p. 230). They vary in thickness up to 2 feet and strike N. 67° E., dip 32° N. The cleavage strikes N. 35° E., dips 12° S.

History and development.—Nothing is known of the history of this opening. It cannot have been more than a prospect.

56. QUARRY.

Location and dimensions.—A small pit lies on the southeast flank of a round hill, 2,000 feet N. 65° W., from the Delabole quarry and 1,500 feet due west of the mill at Delabole. The opening is about 100 feet long and 20 feet wide, and the slate taken from it is piled on the hillside nearby. The cut is very shallow.

On the same hill, to the northeastward of this opening, there are several smaller prospects.

Geology.—Beneath a shallow burden of decayed slate, the beds strike N. 47° E., and dip 14° N. The cleavage strikes N. 47° E., dips 10-15° S. Grain trends N. 47° W., and is vertical.

The beds are very sandy, too much so to permit the development of good cleavage. They effervesce slightly with acid.

History and development.—Nothing is known of the history of this and the adjacent openings.

57. NAGEL QUARRY.

This is a small opening about 400 feet due east of the south Uhler quarry. Glacial material, weathered slate, and water are seen in a small prospect, which is only 15 feet deep. Nothing is known of the history of the opening.

Point Phillip Group

SUMMARY.

Five soft slate quarries are located within a radius of three miles of the town of Point Phillip on the Delaware, Lackawanna & Western Railroad.

All the quarries are abandoned and in none could measurements of the successive beds be made in sufficient detail to establish their exact correlation. A study of the areal geology of the region, however, shows that all these openings, with the possible exception of the St. Nicholas and Beers quarries, lie so close to the north edge of the outcropping middle, sandy member of the Martinsburg that they are thought to have been opened in the Bangor, rather than in the Pen Argyl beds. This conclusion is favored by the sandy character of the slate. In all the quarries studied the beds dip gently and the cleavage more steeply south. The structures in all demonstrable cases thus appear to be the south limbs of (northward overturned?) anticlines, having southward dipping axial planes. No faults were seen, and a detailed study of the jointing was not made.

The products probably included only roofing slate, flagging, and fence posts; although the openings are in the soft belt, they are too small to have supported the extensive operations that justify the erection of a mill.

1.—2. WEST END QUARRIES.

Two quarries, about 200 feet apart, are situated 2000 feet N. 45° E. of the Schall School and about a mile above Newtown up the valley of the west fork of the Bushkill. Both openings are approximately 100 feet square and both are full of water, so that no rock can be seen in place.

The slate found on the dumps north of these openings is somewhat calcareous and effervesces with acid.

These two quarries are said by Mr. Charles Beers of Newtown to have been worked last about 1900 by a Mr. Laub.

3. BEERS QUARRY.

An old quarry lies 1.1 miles due north of Newtown on the west side of the road leading southward from Katellen to Newtown. It is 120 by 40 feet in ground plan. The bedding could not be clearly distinguished but is described by Sanders[115] as having a strike of N.50°E., and a dip of 10°S.; the cleavage strikes N.87°E., dips 62°S. The slate lying on the dump to the south looks quite fresh and has the relatively thick beds and non-siliceous "ribbons" of soft slate.

The property belongs to Mr. Beers of Newtown. Operations were

[115] Sanders, R. H., Geology of Lehigh and Northampton Counties: Pennsylvania Second Survey, D 3, vol. I, p. 103, 1883.

begun here by a Mr. Rolf at least as early as 1890. Slate was taken out later by Mr. Robertson of Pen Argyl. The quarry has clearly been abandoned for a long time.

4. ST. NICHOLAS QUARRY.

About 500 feet southeast of the Beers quarry, on the east side of the Katellen-Newtown road and in the valley of Bushkill Creek, is another small opening, of about the size of the Beers quarry. The quarry walls are not visible, the hole being filled with water. The opening must be shallow, to judge by the size of the dump. The strike and dip are given by Sanders [116] as N.50°E., 15°S. Presumably the history of this operation is much like that of the Beers quarry. Typical soft slate is on the dump to the south.

The beds in which these openings were made are tentatively assigned to the Bangor group because of their nearness to the top of the middle, sandy member of the Martinsburg formation. This correlation cannot be established beyond question, however.

5. YOUNG QUARRY.

This old opening is on the headwaters of Hokendauqua Creek, 1500 feet west of Stahley's Mill and one mile due west of Point Phillip. The dump and hole are hidden by timber from the road immediately to the south. The quarry measures 100 feet N.70°E., by 120 feet N.20° W., and its opposite sides are parallel. The estimated depth is 60 feet. A large waste pile is northeast of the opening on the hillside. Water conceals the bed rock except along the northwest side.

The exposure shows several moderately thick beds, which, to judge by their sandy texture and their nearness areally to the belt of outcrop of the middle, sandy Martinsburg to the south, probably represent the Bangor beds. The strike is N.40°W., the dip 20°S. The cleavage strikes N.85°W., dips 37°S. These relations imply that the quarry is located near, but probably slightly south of the axis of a westward pitching anticline.

Quarrying here is thought by neighbors to have been begun by Charles Young. After unsuccessful operations, the property was sold by George Young, formerly of Youngsville, to Mr. Charles Stahley, the owner of the mill east of the quarry. Production ceased more than 15 years ago. Roofing slate alone was made.

Slatefield Group

SUMMARY.

The quarries of the Slatefield group are all within a mile south of Slatefield on the Lehigh & New England Railroad. This station or the town of Danielsville, about two miles northwest, would be the logical shipping points.

[116] Sanders, R. H., Op. cit., p. 101.

These quarries are all in the soft belt. Actual correlation with the standard section cannot be made with certainty, but by aligning these openings with the Loeb and the Lehigh quarries south of Danielsville, in which the Albion "run" occurs, it is thought that the southern quarries of the Slatefield group can with fair assurance be regarded as having been opened in the Bangor beds, while the Seip quarry is in the Pen Argyl beds, most probably in the Acme or Phoenix "run." This interpretation is strengthened by the sandy character of the beds in the more southerly quarries of the group and by their proximity to the northern border of the outcrop of the sandy member of the Martinsburg.

The beds are variously folded. A striking characteristic is the uniformly steep cleavage dip and hence also the steep dip of the axial planes of the folds; cleavage planes are recorded as dipping 45-63°S. Jointing was not studied. No faults were seen.

None of these quarries are now operated, and there is no probability of the early resumption of work. None save the Labar quarry seems to have furnished much slate in recent years.

1. SEIP QUARRY.

This opening is 1,500 feet S.15°E. from the railroad stop of Slatefield and 1½ miles due west of the St. Joseph School. It is situated south of a northeastward-trending road; the large dump lies on the opposite side of the road. The opening is 125 by 60 feet in areal dimensions and cannot have been over 60 feet deep, to judge by the size of the dump. No slate is seen above the water with which the quarry is filled.

A stone building housing an old boiler is situated about 200 feet north of the opening.

The quarry was last operated by Mr. Henry Seip of Danielsville. It was probably shut down about ten years ago.

2. LABAR QUARRY.

Description.—This quarry is 3000 feet due south of the railroad at Slatefield. It is about 255 feet long northwestward and 165 feet wide. Water fills the hole, but slate is well shown above it in the west corner. Here the beds strike N.67°E., dip 70°S., whereas the cleavage strikes N.60°E., and dips 55°S.; the grain appears to strike about N.20°W. and is vertical. Above the slate is an overburden consisting of 2 feet of slate chips and clay.

The slate seen in the west corner consists of alternating sandy beds 3 inches thick, with poor cleavage, and thicker shaly beds. Some good slate is seen on the large dump to the south. Two big beds yielding good slate are said to have been worked here.

History and development.—The quarry was operated about 20 years

ago by William Loeb of Pen Argyl. It was later sold for taxes to Oliver Labar of Bangor, who operated it 12 or 13 years ago.

The equipment still standing consists of two hoist houses, two masts, a boiler house, a small factory with two planers, three saws, and one rubbing bed. The manner of setting the cables, in the absence of a sufficiently long foundation on which to mount the masts, is of interest. The cables cross the hole in a northwest direction; on the dump they are turned sharply at right angles to their course, being passed over pulleys; they thus extend southwestward before entering the hoist houses, which open to the northeast.

3,—4. QUARRIES.

These two small openings are on either side of the road, half a mile S.20°E., from the railroad at Slatefield. The east hole is 10 feet east of the road, and is 30 feet square. The depth does not exceed 30 feet. In the small exposure of slate on the walls, the beds strike N.70°E., dip 53°S.; the cleavage, N.65°E., dips 48°S. These relations suggest the north limb of a northward overturned anticline.

The small opening 100 feet north of the other and 10 feet west of the road is also filled with water. It measures 25 by 50 feet. No slate is seen in place.

5. LANGENBACH NO. 1 QUARRY.

This quarry is situated approximately 1,000 feet north of the Danielsville-Youngsville road, and 800 feet north of the Langenbach No. 3 opening. It is 100 by 130 feet, a circular hole. It must have been at least 100 feet deep, to judge by the size of the dump to the east. It is now almost completely filled with water. Some slate shows on the west side just below the water, and about 20 feet of slate are to be seen on the east; the latter exposure shows beds which, as estimated from across the quarry, strike N.80°E., and dip 13°S.; the cleavage is thought to strike similarly and to dip 63° S. The grain plane could not be determined.

The slate on the dump shows a tendency to break in well-defined slabs parallel to the beds, is rather sandy, and exhibits catspaws. Its character suggest the Bangor, rather than the Pen Argyl beds, an impression supported by its nearness to the sandy middle Martinsburg to the south.

About 300 feet north of this opening, and largely concealed by its dump, is a small cut showing slate strata, among which is a bed 3½ feet thick. Here the bedding strikes N.78°W., dips 15°S., whereas the cleavage strikes N.60°E., dips 45°S. The grain trends N.41°W., dips 80°S.

6. LANGENBACH NO. 2 QUARRY.

This is a small hole about 100 feet west of the road and 400 feet south of the Langenbach No. 1 opening. It is largely filled by a slump

from the east bank. Slate, some 20 feet in depth, is exposed along a side 30 feet long. The beds strike irregularly, due to slumping; the dip seems to be generally south, from 5 to 25°, but the observations are poor. The cleavage strikes N.80°E., dips 70°S. One big bed 4 feet thick is seen at the bottom of the cut.

7. LANGENBACH NO. 3 QUARRY.

This opening lies about three-quarters of a mile south of Slatefield, and about 40 feet north of the road to Youngsville. It is 70 by 180 feet in size and opposite sides are parallel. The depth is shallow, to judge by the amount of material removed, —not over 40 feet. No slate shows above the surface of the water which fills the opening. The chips on the dump to the south have a good ring, show relatively little rusting, and bear no pyrite or quartz.

This and the two other Langenbach quarries were operated about 35 years ago by the Langenbach Brothers. The slate was shipped through Danielsville.

8. WILLIAMS NO. 1 QUARRY.

This opening is located on the Williams estate, about three-quarters of a mile west of Youngsville, in a field, 500 feet north of the road to Danielsville. It is 50 by 90 feet in size, the opposite sides being roughly parallel. There is water in the bottom, but some 15 feet of slate show in the walls. Viewed from above, the beds seem to strike N.70°W., and to dip 10-20°S. One big bed was quarried here, according to Mr. James M. Marsh, who worked in the quarry.

Operations were begun by Tom Williams of Slatington. In 1892 the quarry was shut down.

9.—10. WILLIAMS NO. 2 QUARRY AND SHAFT.

Two small, shallow pits, about 10 feet apart, are located about 300 feet east of the opening last described. Of these the east one is 40 feet square, the west approximately the same size and probably deeper. Both are filled with water. The westerly opening shows in its southwest wall some slate, of which the strike and dip of the beds is N.80°W., 23°S.; that of the cleavage is N.72°E., 62°S.

Approximately 70 feet southwest of these openings is a shaft. This is said to have been worked to follow the big bed opened in the Williams No. 1 quarry. It is 40 feet deep and 300 feet S.80°E. from the Williams No. 1 opening.

HARD SLATE QUARRIES

Portland Group

SUMMARY.

The four quarries of the Portland group are placed together under that heading because the center of their industrial operations would normally be the town of Portland.

Three of the quarries lie south of the limestone valley that extends west from Portland; the fourth is north of this limestone area. All the openings are in the hard belt and have produced typical hard slate, closely banded, with many thin beds of highly siliceous slate, and with carbonaceous layers less conspicuous than in the soft belt. As the detailed sequence of the beds in the hard belt has not been worked out, the exact stratigraphic location of these quarries is in doubt. The Mount Bethel quarry is probably in strata considerably higher than those of the others.

As will be recalled, the smaller folding in the hard belt is generally intense and these quarries show no clear relation to major folds. It is a striking fact, however, that the cleavage in all three of the openings south of the limestone belt has a steep dip, from 30 to 55°S., which suggests that the fold axes are here more nearly upright than ordinarily. No faulting is seen in any of the openings. No generalizations can be made in regard to joint systems.

The products of these quarries were roofing slate, grave vaults, slate flagging, and fence posts. None of the product was milled.

Of the four pits described none are now operating, nor is there a probability of the early resumption of quarry work.

1. NORTHAMPTON QUARRY.

This is a small quarry in the hard belt situated about a mile north of Portland and approximately 800 feet west of the Portland-Stroudsburg highway on the slope of the hill forming the west bank of the Delaware River Valley. It measures 35 by 15 feet, is roughly rectangular in outline, and shows 20 feet of slate in the walls. The bottom is filled with water. A small heap of waste slate has accumulated east of the opening.

The slate has the typical thin bedding and siliceous "ribbons" of the hard belt. In the bottom of the opening the strata strike N.80°E., dip 42°N.; the cleavage planes strike due east and dip 20°S. Grain trends N.42°W., and dips 80°SW. In the wall of the quarry the beds turn over so as to lie horizontal at the surface.

An old mast and a windlass, with block and tackle, still lie on the dump. The quarry is not described by Sanders[117] so was probably opened since 1878. It is of great importance in interpreting the structure of the region, because it clearly demonstrates the existence between Portland and Slateford of a strip of the lowest member of the Martinsburg formation.

2. MT. BETHEL QUARRY.

This opening is located in the field back of the Mount Bethel Church. It measures 90 by 75 feet and is rectangular in outline. As the quarry

[117] Sanders, R. H., Penn. Second Geol. Survey, D. 3, Vol. 1.

is filled with water, the depth cannot be determined, but was estimated to be 60 feet by Mr. Hartzell of Mount Bethel. The dump rises to the northwest of the opening.

The slate is typical of the hard belt, closely "ribboned," and tending to "rust" on exposure. The bedding strikes N.65°E., dips 12°S.; the cleavage strikes parallel with the beds, and dips 53°S.,—an exceptionally high dip, perhaps induced by the nearby major faulting between this opening and the limestone to the north. The grain plane is not clear, but seems to trend N.30°W.

The quarry has not been operated in many years.

3. PHILLIPS QUARRY.

This is the eastern of two quarries which, about 600 feet apart, are situated on adjacent farms about four-fifths of a mile due east of Mount Bethel. The Phillips quarry is 130 by 65 feet in size and rectangular; it is 25 feet deep to the level of the water standing in the bottom, and probably extends 15 feet deeper.

The slate seen is typical of the hard belt, closely ribboned and with rather papery weathering, but apparently subject to but little rusting. At the surface the beds near the west corner of the opening strike N.65°E., and dip 35°S., but flatten lower down, so as to dip only 5°. Farther south the dip is steeply northwestward. The quarry is thus in the trough of a small asymmetrical syncline, the south limb of which is the steeper. The cleavage (and the axis of the fold) strikes N.42°E. and dips 55°S., an unusually steep dip, such as was also seen in the Mount Bethel quarry. The grain strikes N.38°W. Prominent joints strike N.80-90°W., and dip 70-90°E. A less conspicuous system strikes N.20°W., dips 50-60°S.

This quarry is the property of the farm owners, Messrs. H. and W. Phillips, who live on the land. It has not been worked since 1910 at the latest.

No finished roofing slate is left on the dump. A small engine house stands 60 feet south of the opening.

4. MILLER QUARRY.

This opening is almost triangular in form, its longest side being that to the southwest, which is 190 feet long. The greatest depth of the walls is 20 feet to water level, but, judging by the size of the dump, the quarry is at least 40 feet deeper. A good-sized waste pile, showing closely "ribboned" roofing slate, is near the opening.

The slate shows papery weathering, but is otherwise good. The beds in the northwest corner strike N.10°W., dip 35°S.; cleavage strikes N.63°E., dips 30°S.; grain trends N. 40°W., and is generally vertical. The structure appears to be the axis of a westward pitching anticline, probably complementary to the syncline seen in the Phillips

quarry. Two sets of joints, both striking N.60°E., but one dipping 80°N., the other 65°S., show clearly on the southwest wall and were probably formed simultaneously. Their general parallelism with those observed in the Phillips quarry is noteworthy.

This quarry belongs to Mrs. Stella Miller, the owner of the farm. Between 15 and 20 years ago it was operated under lease by a company with offices at Newark, N. J. No machinery remains.

Unclassified

QUARRY.

About six-tenths of a mile due west of the road intersection at Johnstonville (Delaware Water Gap sheet) and about 400 feet north of the highway, on the farm of Mrs. Miller, is a hole now full of boulders and showing slate only in fragments, not in place. The slate chips appear to be closely ribboned, like hard slate, but it is thought that this opening, like the Batt quarry south of Wind Gap, is in a lens of slate beds between the sandy layers of the middle Martinsburg. This opening is said to have been worked for slate on a small scale some time ago.

South of the residence of Mrs. Miller two openings were once operated, and closely ribboned hard belt slate was obtained. These old excavations are now filled up.

Flicksville Group

SUMMARY.

Several quarries are dotted over the outcrop of the hard belt in the neighborhood of Factoryville and Flicksville. Normally their shipping center would be Flicksville, on the Martins Creek branch of the Bangor & Portland (Delaware, Lackawanna & Western) Railroad.

The slate in these quarries is in the hard belt, but some of it is characterized by especially thick beds, suggesting those in the Batt quarry. The exact stratigraphic position of these quarries cannot be determined.

Several of the openings display complex folding of the beds around axial planes that are almost horizontal. Otherwise no general statement as to the folding involved can be made.

The cleavage shows the usual strike, generally N.60-80°E. A fairly generally developed system of joints strikes approximately due north, dips vertically or nearly so.

The quarries of this group have not been operated in several years and many of them were opened long ago. All are now abandoned. The openings, with the exception of the True Blue quarry, are not large and their production was relatively unimportant. The yield was roofing slate, fence posts, flagging, and grave vaults.

1. PYSHER QUARRY.

This small and long abandoned opening is one mile N.60°E. from Flicksville in a field about 150 feet east of the road, on the farm of Mr. Paul Pysher.

The hole is triangular in outline and 5 feet deep to water level, but thought by Mr. Pysher to be 22 feet deep to the actual bottom. The beds dip gently south; the strike, however, could not be obtained. Cleavage strikes N.48°E., dips 40°S.; presumably the structure here is the north limb of an anticline.

The quarry was opened 40 years ago by Mr. J. G. Pysher. Operations continued for 3 years. Roofing slate was produced for local use only, an old-fashioned horse derrick being employed in quarrying.

2. DOSTER QUARRY.

This opening is on the Doster estate, about 800 feet up the valley of the small stream that crosses the highway 2000 feet south of Flicksville. The opening is 80 feet in diameter and roughly circular; a small re-entrant is cut into the northwest wall. The slate is exposed for a depth of 35 feet on the southeast wall, but the surface of the ground declines in a northwest direction. The total maximum depth of the opening is probably 60 feet below the surface.

The slate is typical, closely "ribboned" hard slate. The beds could not be sufficiently well distinguished to determine the dip and strike, but it is believed they incline about 12°S. The cleavage strikes N.70°E., dips 28°S. Grain trends N.53°W., dips 70°E. Twelve joints were counted, seven striking about due north dipping vertically, and five striking N.75°E., also vertical in dip.

The opening was made by H. A. Doster of Bethlehem. No slate has been quarried for over 30 years.

On the dump stands an old boiler. Otherwise no equipment remains.

3. WAGNER QUARRY.

This pit lies seven-tenths of a mile south of Flicksville, 70 feet east of the main Martins Creek highway. It is a circular hole 50 feet in diameter, with a small dump west of the road. The depth is probably 50 feet at most. A little slate shows in the southeast wall, but is not accessible for measurement. The quarry is concealed by a heavy growth of vegetation.

According to Mr. Josiah Ruch of Flicksville, slate was first quarried here in 1875 or earlier by John O. Wagner of Easton. Operations ceased after 3 years of sporadic work. There was no commercial production.

4. TRUE BLUE QUARRY.

Location and dimensions.—This opening lies about a quarter of a mile N.35°E. from Nazareth Junction, and west of the Martins Creek

highway. The quarry is 185 feet by 275 feet in size. The northeast part of the quarry is greatly caved, and the southwest part seems deepest, but is filled with water so that the true bottom is not visible and only 15 feet of slate are exposed in the walls. The large dump to the northeast is readily seen from the highway.

Geology.—The slate is typical, closely "ribboned" hard slate. It is partly sandy and "rusts" (turns brown) somewhat upon weathering. The best beds are on the southeast. Pyrite is not uncommon and upon weathering yields a film of iron sulphate on the re-entrants of the quarry walls.

At the surface the beds strike N.60-80°E., and dip 35°S. near the north end of the northeast wall, but can be seen to reverse themselves to a north dip about 10 feet below the surface, then to dip south again near the bottom of the opening. Cleavage strikes N.65-75°E., dips 35-40°S. In places quartz stringers parallel the cleavage planes; this is especially noticeable on the southeast wall. The grain strikes N.60°W., dips 70°NE. In the northeast wall joints trend N.10°W., dip 75°SW., and are very conspicuous.

History.—This quarry was opened about 1865 by a company consisting of Herman A. Doster of Bethlehem, and others. The property is owned by the heirs of the Charles Daniels estate. In 1900 the quarry was leased to Rice and Yale of New York City. In 1904 this lease was transferred to Mr. J. W. Cook, who operated for the Pittsburg Slate Company; quarrying continued until 1910. There was considerable testing by drill in the bottom. Then the quarry was leased by Thomas Danner of Easton, who, after operating a few years, finally shut it down.

The products included grave vaults, grave covers, and roofing slate.

5. FRIEDMAN QUARRY.

The Friedman quarry is on the hill slope west of Martins Creek, northwest of Nazareth Junction, northeast of Factoryville, and 1,500 feet due west of the True Blue quarry. It is 45 by 60 feet in size and 25 feet deep to water level. The waste from the hole is scattered nearby.

The slate is typical hard slate, closely ribboned and siliceous. The beds strike N.78°E., dip about 8°S., but were not accessible for accurate measurement. The cleavage dips 27°S., strikes N.85°W. Grain appears to trend N.55°W. A set of joints strikes N.55-60°E., dips 80-90°N.

The quarry was opened on a lease about the year 1910 by the Friedman Brothers of Scranton, but no slate was ever sold. The usual machinery was used, but has since been disposed of.

6. DELABOLE QUARRY.

A hard belt slate quarry lies 1.1 miles due west of the crossroads at Factoryville. It is in the valley of a small stream, about 1000 feet from the Werkheiser-Factoryville road. The opening measures about 150 by 80 feet, and is roughly rectangular, but with a corner projecting into the rectangle from the southwest side. The depth is probably 75 feet, to judge by the size of the dump, but it is now so completely filled with water that no bed rock shows.

The slate on the dump suggests somewhat that seen at the Batt quarry, 1½ miles south of Wind Gap. The largest bed is 2 feet thick, and there is much close "ribboning" with highly siliceous laminæ; some carbonaceous "ribbons" up to 2 inches in thickness occur.

As no slate outcrops, the actual dip and strike of beds could not be determined. Sanders[118] gives the bedding as striking N.60°E., dipping 80°S.; the cleavage strikes N.60°E., dips 25°S. The grain, to judge by the form of the quarry, is N.38°W.

This opening was made about 1875 by Samuel Rice. No machinery remains on the dump.

Belfast—Edelman Group

SUMMARY.

The quarries of this group are within a radius of 2½ miles of the village of Edelman on the Delaware, Lackawanna & Western Railroad. All are most convenient to this railroad; shipments may be made from Rasleytown, Edelman, Werkheiser, or Belfast Junction. Supplies are purchased from Belfast, and here also reside the quarry workmen.

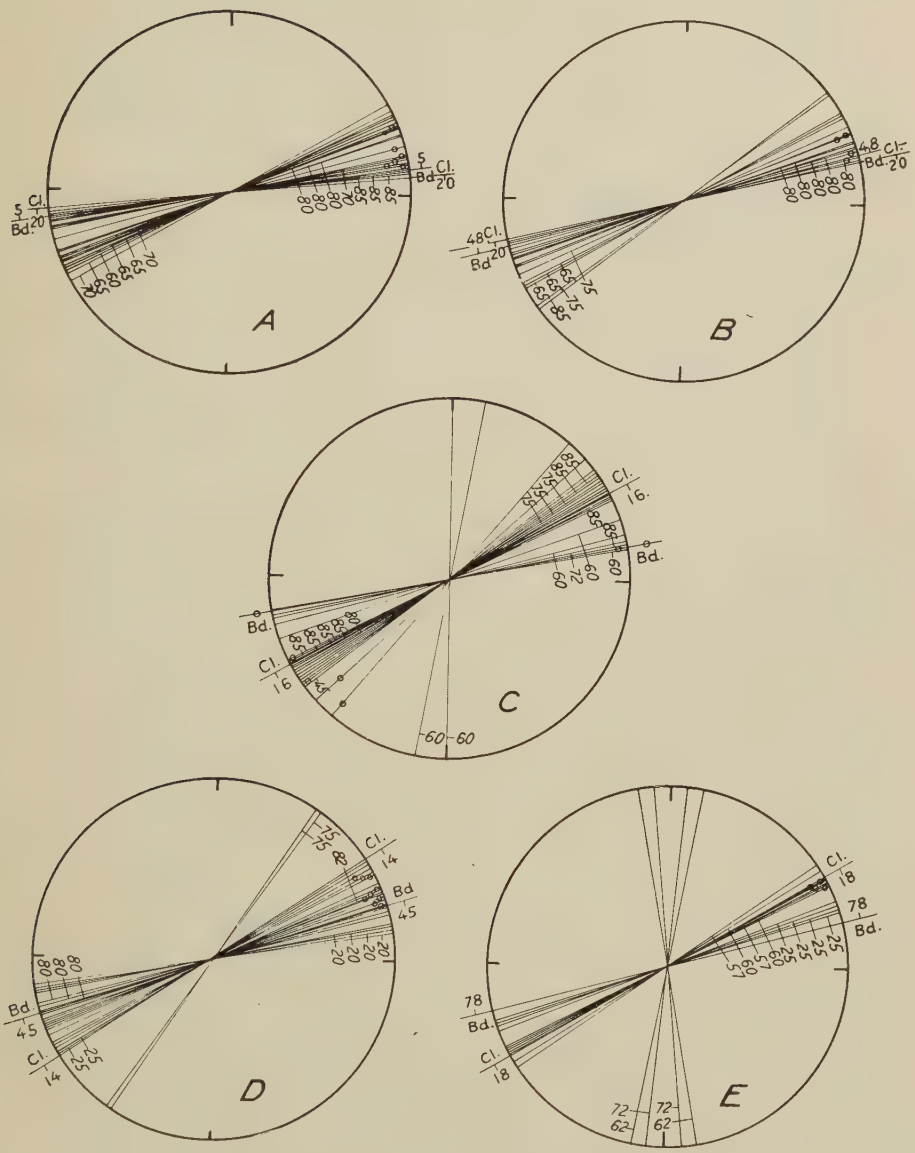
All these quarries except the Batt quarry are in the hard belt and produce typical hard slate. Some, like Numbers 18, 19, and 20, are low down in the lowest member of the Martinsburg, but others are operating in much higher beds. The Batt quarry is thought to have operated in a lens of rock similar in most qualities to hard slate, but lying between beds of middle Martinsburg sandstone.

The structures exposed in the openings are too variable to permit any generalizations. The strike of the bedding is commonly about N.80°E., whereas the cleavage tends to have a more northerly course and dips gently south.

In at least two quarries there are illustrations of movement along cleavage planes, what might be called "cleavage plane slip." A movement of this type is described from the Edelman and Belfast quarries, and is thought to be present at depth in the Northampton quarry.

[118] Sanders, R. H., Op. cit., p. 98.

PLATE XXXI



STRIKES OF JOINTS IN HARD SLATE QUARRIES

A. Belfast, upper levels. B. Belfast, lower level. C. Chapman Standard. D. Chapman, upper levels, east hole. E. Chapman, bottom, east hole.

One joint system is especially prominent in all openings, that striking N.55-80°E., and dipping vertically. The following table illustrates the fact mentioned.

Generalized strike and dip of prominent joint systems in several quarries of Belfast-Edelman group.

Strike	Dip	Strike	Dip
N.10°E.	50°S.	N.70°E.	45°N.
N.55-70°E.	Vertical	N.80°E.	80°S.
N.60-80°E.	Vertical	N.55-70°E.	Vertical
N.55°E.	Vertical	N.60-80°E.	65°S.-vertical
N.75°E.-80°W.	70°S.-vertical	N.80°W.	Vertical

On the whole, it may be said that in these quarries the jointing is very regular.

In the openings of this group, production, being entirely hard slate, is confined to roofing slate, slabs, fence posts, grave vaults, and, rarely, table tops; of these, roofing is by far the most important.

Only two quarries were active in 1923-24, the main Belfast quarry and the Edelman quarry. A small production in early 1923 came from the Theo. Whitesell and Northampton quarries.

1. BATT QUARRY.

This old quarry is eight-tenths of a mile N.60°W., of the church at Rasleytown. It is 60 by 100 feet in size, the opposite sides being parallel. Being filled with water, it exposes only a few feet of slate. The beds strike due east, and are closely folded. Cleavage strikes N.70°W., dips 10°S. Grain trends N.47°W. Well developed joint planes strike N.37°E. and dip vertically; one such forms the northeast side of the opening.

The "ribbons" in this slate show much more carbonaceous matter than is usual in the hard belt, yet are closely spaced and generally half an inch or less in thickness. The slate gives the appearance of being intermediate in character between the slates of the hard and soft belts. It is thought that this opening is in a lens of slate between the sandy beds of the middle member of the Martinsburg formation.

The quarry is on the old Batt farm. It was operated about 25 years ago. No machinery remains on the dump.

2. GARR QUARRY.

This opening, which is 175 by 125 feet, lies on the west bank of Bushkill Creek and east of the Delaware, Lackawanna & Western Railroad, about three-quarters of a mile south of Rasleytown. The depth is not known and the hole is now filled with water. The beds just across the stream here strike N.75°E., dip 75°S., while the cleav-

age strikes N.85°E., dips 35°S.; presumably the same structure is present in the quarry here described.

The slate on the dump has a good ring, and shows relatively few ribbons for hard slate; quartz veins are common.

The quarry is equipped with two cables and masts. It was last operated in 1912 under the management of Mr. Garr of Bloomsbury, N. J.

3. LEHR QUARRY.

About 1,000 feet N.80°W. from Edelman a quarry measuring 90 by 70 feet is located. The depth is 25 feet to water level, but may be at least 15 feet deeper. The beds strike N.48°E., dip 10°N.; cleavage strikes N.82°W., dips 18°S. A single cable still stretches across the opening. Some roofing slate is piled on the dump.

The quarry was opened in 1900 by F. H. Lehr. Operations ceased in 1907.

4. EDELMAN QUARRY.

Location and dimensions.—This quarry is about 300 feet west of the railroad and 500 feet north of the station of Edelman. The older part measures 200 feet N.48°E., by 225 feet N.38°W.; south of this, stripping has developed a working level measuring 85 feet N.53°W. by 125 feet N.45°E. The old part of the opening is filled with water, but the slate rises well above the water level in the walls; this part of the quarry was 150 feet deep. A large dump is south of the opening.

Geology.—In the southeastern side the glacial overburden is about 10 feet thick, consisting of boulders, some well rounded, set in a matrix of sandy clay that bears slate flakes and occasional lenses of pure clay from a half to two inches in thickness. These sediments suggest stream deposits washed from the front of the ice sheet.

The beds in this quarry are thrown into a series of open folds with horizontal axial planes, two adjoining anticlines and the intervening syncline being visible on the northwest wall. In one place the thickening produced by such folding swelled a bed 3½ inches thick where the dip is 30° (that is, on the limb) to 7½ inches on the axis of the fold.

The strata in the present working level strike N.65°E. and dip variously. The cleavage strikes N.65-80°W., dips 10° or less to the south. Grain trends N.53°W. A series of joints strikes N.10°E., dips 45-55°S.; another system strikes N.55-70°E., dips vertically, and cuts off the joints of the set first mentioned.

In addition, the old hole, especially along the western walls, shows an almost flat-lying slippage plane striking N.65°E., and dipping 8-10° S., and thus parallel with the cleavage. In the present working level a similar plane is seen. Here the cleavage is curved, and there is evidence of movement along a series of closely spaced cleavage planes. A stringer of quartz and coarsely crystalline calcite follows this dis-

turbed zone; at intervals the wrinkling of the cleavage is unusually conspicuous and a spherical or lenticular mass of calcite and quartz, irregular in outline and generally elongated parallel to the cleavage, if at all, appears. Plate VIII, B, shows a similar feature as seen in the Belfast quarry (see p. 69).

History and development.—This quarry was opened by the pioneer quarryman Edelman, after whom the railroad station was named, about the year 1870. The operating company abandoned it in 1900. In 1923 the Theo. Whitesell Hard Vein Slate Company stripped the surface immediately south of the hole and began to quarry slate. This company is capitalized at $50,000 worth of stock valued at $10 per share. The chief owners of the stock are Messrs. Wm. Tomkin, Ashley Odenweiler, John R. Chidsey, Ray G. Whitesell, and Richard S. Whitesell. The charter was issued in 1923.

Several shanties are in operation. Two masts and cables are used. Roofing slate is produced.

5. BARNETT QUARRY.

This small prospect lies about 840 feet N.75°E. from the station of Edelman on the Delaware, Lackawanna & Western Railroad. It is 10 feet deep to the water level and the hole probably extends 20 feet deeper. The beds strike N.80°E., dip 12°N.; the cleavage strikes about due east, dips 20°S.

The opening was last worked in 1887, when a lawsuit as to property ownership compelled the stopping of operations.

6. PENNSYLVANIA QUARRY.

The opening is immediately east of Little Bushkill Creek, 500 feet south of the station of Edelman. The measurements are 300 by 250 feet. The upper 5 feet are badly weathered slate chips, and below this, solid rock appears. The strike and dip of bedding and cleavage, respectively, are N.80°E., 15°N., and N.50°W., 40°S. The slate seems to be good except for pyrite and calcite along fractures.

This quarry was first opened in 1895 by Mr. G. W. Geiser of Easton. It is on the property of the Pennsylvania Hard Vein Slate Company, the chief stockholders being Messrs. Lieberman, Osterstock, and Geiser, and Dr. Heller.

In 1914 the quarry was sold to Mr. R. N. Male of Pen Argyl.

7. SEEM QUARRY.

This and the Allen quarry lie 1,200 feet west of the Little Bushkill and equally distant from Edelman and Werkheiser on the Delaware, Lackawanna & Western Railroad. The northern opening is the Seem quarry. It measures about 150 by 100 feet and is separated from the Allen quarry by a wall 8 feet wide along its southwest side. The depth is not known, but 25 feet of slate show above water level. At the sur-

face the hard slate beds strike N.80°E., dip 20°N.; the cleavage strikes N.50°W., dips 13°S. Prominent joints trend N.60-80°E. and dip vertically.

This quarry is the property of Mr. J. H. Seem of Bath. It has not been in operation for the last 20 years.

8. ALLEN QUARRY.

This lies close to the Seem quarry; the wall that forms the southwest edge of the latter is the northeast side of the opening here described. The Allen quarry is a rectangular hole about 100 feet square, with a projection from the south corner. It is said to be the deeper of the two openings. It shows the same structural features as the Seem quarry. The overburden is about 4 feet of weathered slate.

This quarry was first operated by Teeny Allen of Portland. In 1910 Charles Schuman of Bangor attempted quarrying and milling, but failed.

9. NORTHAMPTON QUARRY.

Location and dimensions.—This is a large opening at least 175 feet deep to water level, and said to have been 350 feet deep when working. It is 500 feet northeast of the station of Werkheiser on the Delaware, Lackawanna & Western Railroad. In ground plan it is rectangular and measures 400 by 225 feet, the longer dimension extending N.55°E. A smaller quarry lies 400 feet S.20°E. of that described. It is 100 by 200 feet in area, the larger dimension extending northeast. A large dump lies southwest of the main opening.

Geology.—The general strike of the beds in the large opening is N.80°E. to N.80°W. The dip is very variable, being generally northward, with repeated close folds. Cleavage strikes N.50°E., dips 5 to 10°S. At depth the cleavage is good, apparently beneath a flat joint or cleavage plane that bears calcite and closely resembles the cleavage slip seen in the Edelman quarry. The close jointing proved disadvantageous to quarrying. The bottom is not accessible and was therefore not studied in detail.

The smaller hole shows beds striking due east, and dipping 12°N.; the cleavage strikes N.70°E., dips 12°S. There is less overfolding here than in the larger quarry. Vertical joints, tending to curve downward, strike N.55°E. There are also numerous minor curved joints which seriously interfered with quarrying.

History and development.—This opening was made by the Northampton Hard Vein Slate Company, which was formed in 1885 and consisted of Theo. Whitesell, Geo. W. Geiser, Wm. H. Smith, Chas. P. Young, and Robert D. Young, all of Bangor and Easton. The corporation was capitalized at $25,000. The quarry was operated until

the spring of 1923, even through the period of the Great War, but the partnership was dissolved in 1924.

The small hole to the southeast of the main quarry was more in the nature of a prospect, though carried to a depth of 100 feet.

At the time of the writer's last visit the masts were being removed and all machinery taken away. A little excellent roofing slate remained on the dump.

10. QUARRY.

Just south of the road from the Northampton quarry to Werkheiser, and east of Little Bushkill Creek, is a small opening 60 by 80 feet in ground plan. Above the slate in this opening are 15 feet of fine clay, set with pebbles of sandstone that vary in diameter up to 3 inches, and with flakes of slate 8 inches or less in length. Rarely the pebbles are striated. The beds in the opening strike N.80°E., dip 65°N., with at least one close fold showing in the north wall. Two N.60°E. joints are seen. Some good roofing slate lies on the dump.

This opening was a part of the operations of the Northampton Hard Vein Slate Company. Mr. R. S. Whitesell of Easton says it was regarded more as a prospect than as a quarry.

11. QUARRY.

In the valley flat, just west of the Little Bushkill and about half a mile south of the station of Werkheiser, is an old slate quarry measuring 70 by 40 feet in area. It is said to have been 65 feet deep. Water now fills it to the top. The bed rock cannot be seen. A few old slates on the dump seem to be of good quality. Mr. R. S. Whitesell says that a drill core was obtained in this opening and at 50 feet below the quarry bottom (total depth 115 feet below surface) a plane of movement with clayey guage and closely spaced joints was encountered. This apparently represents another cleavage slip.

This opening has long been deserted.

12. THEO. WHITESELL QUARRY.

Location and dimensions.—This large opening is about 4,000 feet S.30°E. from the station of Werkheiser and 2,000 feet east of Little Bushkill Creek. It is irregular in shape and measures roughly 240 feet N.20°W. by 285 feet N.50°E.

Geology.—The beds are virtually horizontal. There is none of the repeated overfolding seen in the Northampton quarry. The "ribbons" seem to be somewhat farther apart, and less conspicuous than in most hard slate. The cleavage strikes N.80°E., dips 18°SE. Grain

trends N.50°W. Prominent joints strike N.75°E. to N.80°W., with dips varying from 70°S. to vertical. A less conspicuous system strikes N.70°E., dips at angles of about 45°N. A few irregular joints strike N.30°E. The two main systems are closely contemporaneous, as they cut each other indiscriminately. The outstanding feature of these joints is the general parallelism in their strike.

History and development.—This quarry was operated by the Theo. Whitesell Company of Easton, the main stockholders of which are Messrs. R. G. Whitesell, R. S. Whitesell, E. W. Laub, and E. P. Laub of Easton and Belfast. The company was incorporated in 1916, but the quarry was opened as early as 1890 by Theo. Whitesell. The corporation was capitalized at $12,500. Operations were fairly successful, but there was some curvature of the cleavage. The work ceased in 1924.

The equipment included 3 cables and masts. A full line of roofing slate was produced.

13.—14. QUARRIES.

Two small prospect pits lie immediately east of the Theo. Whitesell quarry. The northern is by far the larger opening. In it the beds are horizontal and the cleavage strikes N.80°E., dips 18°S. The grain trends N.40°W., dips steeply northeast. A set of joints striking N.80°E., and dipping 80°S. is conspicuous. The history of the ownership of these smaller openings is similar to that of the Whitesell quarry.

15. PRITCHARD QUARRY.

This old, deserted quarry lies S.25°E. of the station of Werkheiser, up a small valley that enters the Little Bushkill from the east. The opening is irregular in shape, its maximum dimensions being 200 by 80 feet and its greater length extending about due east. Water rises to within 5 feet of the surface.

The slate is typical hard slate, closely banded. The bedding strikes N.72°E., and dips 15°N. Cleavage planes strike N.35°E., dip 18°S.

The quarry was operated in the years 1854 to 1878 by Mr. C. J. Pritchard of Easton. Some 50,000 squares of slate were produced.

16. OLD BELFAST QUARRY.

Location and dimensions.—This small quarry lies 700 feet west of the Belfast-Wind Gap highway, due west of the Belfast school. It measures 85 by 125 feet, the greater length being in the direction N.42°W. The opening is rectangular. Its depth is 20 feet to water level, where the walls are highest, but probably extends 60-80 feet deeper. Along the northeast side stripping has been done, apparently looking toward further quarrying.

Geology.—The stripping mentioned exposes 1 to 5 feet of drift, con-

sisting of boulders of sandstone, conglomerate and quartzite. Beneath this overburden the bedding is horizontal in the south end of the opening and dips gently north at the north end. The cleavage strikes N.80°E., dips 28°S.; grain trends N.48°W. A system of prominent joints, striking N.55-70°E. and dipping vertically or nearly so is well developed; joints of this set form the longer walls of the opening.

History and development.—The history of this quarry is linked with that of the new Belfast quarry to the west and will be described later.

One cable and pulley still remain at the pit.

17. BELFAST QUARRY.

Location and dimensions.—This large quarry lies due west half a mile from the schoolhouse in Belfast, north of the road from Belfast to Jacksonburg, and east of Bushkill Creek. The opening, with several jogs in its walls, is roughly rectangular, measuring in ground plan 185 feet in its greater (northeast) length by 137 feet northwestward. It is about 150 feet deep to the lowest level, which is partly under water. Operations were progressing in 1924 on several sub-levels between 100 and 150 feet deep, and on an upper "piece," 30 feet below the surface. In 1926 the quarry was shut down.

The large dump is west of the opening, between it and the stream.

Geology.—The fresh slate is covered by an overburden of 2 to 3 feet of decayed slate and chips, upon which rest 8 feet of glacial clay bearing faceted quartzite boulders. Fresh slate, suitable for sale, is quarried 15 feet below the surface.

The beds are typical hard slate throughout the quarry; on the lowest level, however, the beds appearing on the working piece are somewhat more siliceous and not profitably quarried.

At the surface the strike is N.80°W., dip 7° N. On the next lower level the dip and strike are similar, but on the lowest working level (depth 100 feet) the strata take a sharp turn, dipping first 20°N., then, at a depth of about 120 feet, 45°S., and finally, in the very deepest part of the quarry, being again reversed, 3°N. Approximately the same strike is maintained by the beds throughout.

The cleavage strikes approximately due east, and varies in dip from 5 to 22°S. Grain trends on an average N.40°W., and is vertical.

The jointing in this quarry is very regular. All joints strike northeast, and by far the greater part between N.60° and 80°E. The dips are generally steep, varying between 65 and 90°S. Between two larger joints it is common to find a set of smaller compensating joints, their strikes making angles of 45° or less with the main joints and their dips about the same in magnitude and direction as those of the latter. For joint diagrams see Plate XXXI, p. 243.

About 5 feet below the lowest working level and 10 feet above it respectively are two "floors" (in the vernacular of the quarrymen) or cleavage slip planes. Plate VIII, B, is a photograph of the lower cleavage slip. This is a zone about 10 inches thick (at right angles to its plane) and parallel with the cleavage. Above and below it the slate is solid and the beds dip 20°N., the cleavage 20°S. In the cleavage slip itself the movement has accentuated the cleavage, so that the slate breaks into thin slivers. There is little tendency for cleavage planes actually to curl, but they are more irregular than those beyond the zone of the slip. The slip zone contains lenticular masses of quartz with carbonaceous and sericitic inclusions, the lenses being inclined southward more steeply than the cleavage. These relations, as well as the offsetting of joints above and below the zone of movement and the fact that the beds above the zone dip northward while those below dip steeply south, suggest that there has been horizontal movement along the cleavage slip zone, the upper side moving northward.

In the higher of the two zones of movement there are not merely quartz lenses, but quartz-filled gash joints, dipping parallel with the lenses. In this case the joints above the slip zone are offset northward 4 inches above those below.

Numerous irregular joints or "scows," roughly parallel in strike with the grain, but dipping 30-60°NE. or SW., are seen in this opening.

History and development.—Slate was first quarried here in 1884 by Amen Hughes. Subsequently the quarry passed into the hands of Mr. G. F. Messinger of Tatamy. In 1918 the property was purchased by Mr. W. I. Gold of Nazareth; since its acquisition by Mr. Gold the quarry has been in continuous operation.

The equipment includes three masts and cables, of which two were in use in the summer of 1924. Eight shanties were operating at the time mentioned. The products include roofing slate, flagging, fence posts, and grave vaults. Roofing slate is made in sizes up to 12 by 28 inches. Fence posts sell at about 30 cents apiece.

18. QUARRY.

At Belfast Junction south of the secondary road that crosses the Little Bushkill here, and east of the stream, is a small rectangular opening, 25 by 30 feet in areal dimensions and 25 feet deep. Slate showing on the wall strikes N.60°E., and dips 20°S., but Mr. R. S. Whitesell of Easton asserts that cement rock was encountered at depth. It thus appears that the opening is near the base of the Martinsburg formation.

19. HENRY QUARRY.

This old opening is 2,000 feet southeast of Filetown and about 1¼ miles due west of Belfast Junction, on the property of Mr. G. W. Metz. It is about 80 by 120 feet in area and approximately 40 feet deep. Water now fills the opening.

In the northeast corner the cleavage strikes N.50°E., dips 13°S. The bedding is nowhere accessible to accurate measurement, but appears to strike about N.65°E. (estimated), with a dip of 50°S. Grain trends N.48°W., dips 80°S. Some poorly developed joints strike N.80°W. and are vertical.

The slate on the dump shows moderately thick beds. Some roofing slates, already punched, are on the dump.

The quarry was last operated about 40 years ago. At that time Edward Henry was in charge, a lease having been secured from Mr. J. Moyer, who owned the property. The product was good roofing material that found much favor, especially in Nazareth.

20. QUARRY.

Halfway between Filetown and Cherry Hill and about 300 feet northwest of the road, is a small opening measuring 35 by 15 feet and 5 feet deep to water level. The beds strike N.70°E., dip 40°S., whereas the cleavage strikes N.80°E., dips 11°S. Typical hard slate is exposed. The structural relations are those of the north limb of a northward overturned anticline.

The opening is clearly no more than a prospect. Its history is not known.

Chapman Group

SUMMARY.

A number of quarries in the hard belt are scattered throughout the area drained by Monocacy Creek and lying between the outcrop of the "cement rock" or Jacksonburg limestone to the south and the southern fringe of the middle, sandy member of the Martinsburg formation. These quarries are lumped together under the title of Chapman group, merely because the present (and probable future) production centers around the station of Chapman on the Lehigh & New England Railroad (Figure 39). The most logical and common commercial center for the quarries, however, is the town of Bath.

The beds exposed are all in the hard belt, and, as separate beds in this lowest member of the Martinsburg bear no marks by which they can be readily distinguished from those above and below, the correlation of the strata in one quarry with those in another is impossible. The hard slate member is thrown into repeated folds, which, though generally small, are, as far as the quarries expose them,

generally not very "tight," that is, they have large opening angles. The cleavage is regular, and generally strikes N.55-80°E., with gentle southward dips.

Faulting is rare, only one case being recorded, and even in this instance the displacement does not exceed a foot. Some slippage along

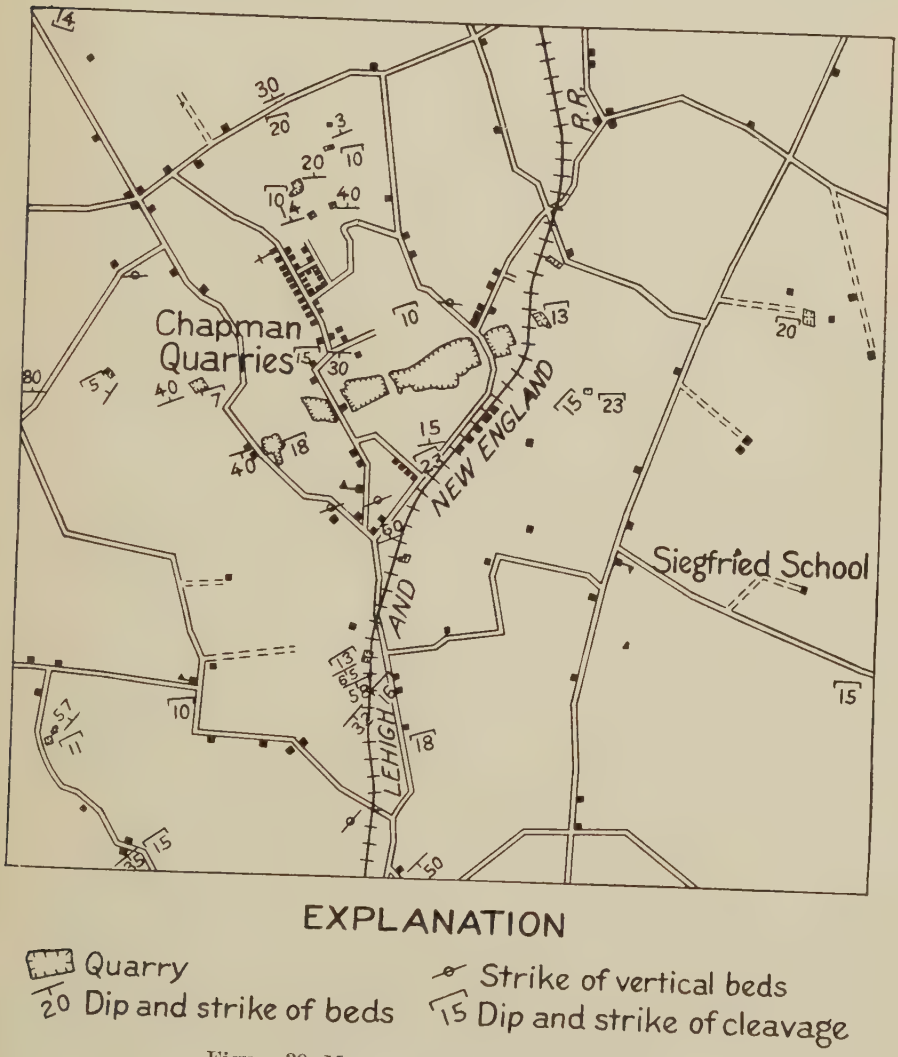


Figure 39. Map of Chapman and environs.

cleavage planes is suggested in the Chapman Standard quarry and in the two Chapman quarries.

The jointing was studied in great detail only in the three openings now operated; the strike of most of the joints is about N.60°E., and

dips are vertical. This system is not conspicuous, and is generally compensated by joints with similar strikes but gentle dips.

The grain, as usual, trends northwest.

The outstanding products of the Chapman group of quarries is roofing slate of the typical "ribboned" variety, but slate for various structural purposes for which milling is not needed is also obtained. This includes grave vaults, fence posts, and wall boards.

Three openings are now operated in this group, all by the Chapman Slate Company.

1. GRABER QUARRY.

This pit is in the stream valley about a mile due west of the Chapman quarry and an equal distance south of Klecknersville. It is a small opening, long deserted, showing a little closely-ribboned slate on the dump. No slate is seen in place above the water which fills the hole.

2. THE WELSHMAN'S QUARRY.

This opening is N.65°W. seven-tenths of a mile from the station at Chapman, and about 1,000 feet west of the Ryan quarry. It is a small pit, about 100 feet in the greatest length, irregular in shape. The depth is probably not over 20 feet.

In the southwest corner the beds strike N.40°E. (?), dip 12°N.; the cleavage strikes N.60°E. (?), dips 5°S. The slate appears to be of good quality, but very irregular joints, which probably hindered quarrying, are seen on the walls.

3. RYAN QUARRY.

This opening is 1,200 feet due west of the Chapman Standard quarry and is west of the road from Chapman to Klecknersville. It is 200 feet square. The depth was at least 75 feet. A large dump is west of the hole. Water now stands in the opening.

In the southwest corner of the quarry a little slate is seen. The beds, though not accessible, are estimated to strike N.70°E., and to dip 40°N. Cleavage appears to dip 7°S. Grain trends N.38°W. A very regular vertical joint, striking N.60°E., forms the southeast quarry wall.

No machinery remains on the dump. The slate is closely "ribboned" and appears to be of good quality, with no excess rusting, quartz-filled crevices, pyrite, nor curved cleavage.

Quarrying was dicontinued in 1893. The land is now the property of the Wilbur Trust Company, of Bethlehem, Pa.

4. BETHLEHEM QUARRY.

This quarry is about 400 feet southwest of the Chapman Standard and just north of the road from Chapman to Klecknersville. It is

160 by 60 feet in size, the greater dimension extending northeast; the opening is virtually rectangular, with minor irregularities, and is filled with water; some slate shows above water level on three sides.

The slate exposed is typical of the hard belt. At the highest point in the quarry wall the beds strike N.70°E., dip southeast about 40°, then the dip decreases, and steepens again lower down (see Figure 40); in this folding there is a notable lack of thickening of beds on the crests and troughs.

The cleavage strikes N.57°E., dips 18°S. Grain trends N.40°W. The joints are notably regular and fall into one system: all major joint planes strike N.62-68°E., and are vertical. Between these major

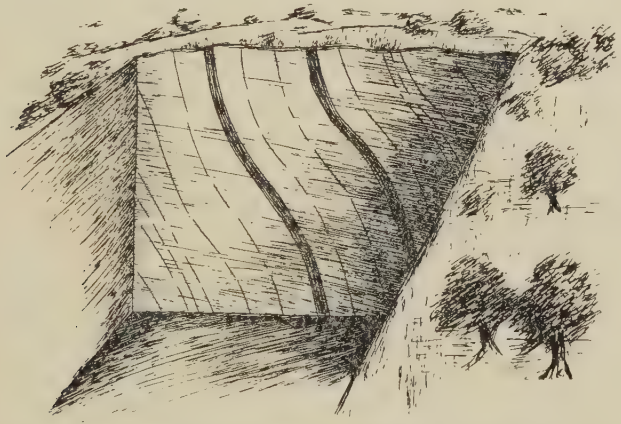


Figure 40. Northeast wall of Bethlehem quarry, to show turn in dip of beds. From southwest side of opening.

fractures there are commonly minor crevices striking N.50-60°E., which stop abruptly at their intersections with the major fractures.

No machinery remains. This quarry was opened before the Chapman Standard, and work was abandoned approximately at the time of the beginning of operations in the latter quarry.

5. CHAPMAN STANDARD QUARRY.

Location and dimensions.—The Chapman Standard quarry is one of the few in the Chapman group now being operated. It is 250 feet southwest and virtually along the strike from the large Chapman quarry. In ground plan it is a rhombic opening about 250 feet in length and width. The depth is 130 feet to water. On the northwest side the wall slopes steeply from the surface to the bottom of the quarry; everywhere else the sides are sheer. When visited, the quarry was being worked on one level only—that in the south corner—where a piece was being removed about 40 feet above the water in the bottom.

A large dump is west of the opening.

Geology.—The thin overburden consists of weathered slate. Much has been stripped in the early quarry operations.

The strata exposed are all typical of the hard belt, being closely "ribboned," with many siliceous layers and only a few beds exceptionally rich in carbonaceous matter.

The opening exhibits well the folding characteristic of the lowest members of the Martinsburg formation. At the very surface, in the north corner, the strike is N.80°E., and the dip 75°S., but in the south corner the dip is northward, owing to the emergence between these points of an anticlinal axis that dips south. Midway along the northeast side, a synclinal axis is encountered in the descent. Below this, at 50 feet of depth another anticlinal axis is seen, and at a depth of 80 feet one more syncline, the beds here striking N.75°E., and dipping 80°N. These folds (see Figure 41) are open, with

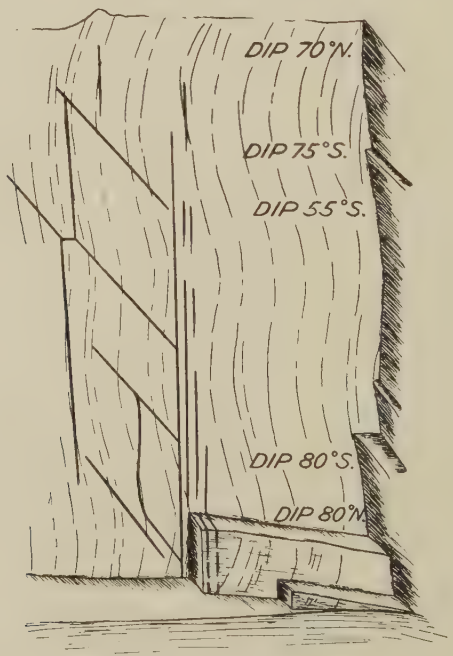


Figure 41. Sketch of northeast wall at east corner of Chapman Standard quarry, as seen from floor of quarry. Shows changes in dips of bedding, and intersection of joints dipping 45°S. with others dipping vertically.

little thickening, if any, on the crests and troughs.

The cleavage strikes N.60-70°E., dips about 15°S. wherever observed. Some is curved. Grain trends N.50°W., and is vertical.

Jointing was studied in detail. Of 23 joints recorded in the bottom,

20 strike between N. 53 and 80°E., and all except one have a dip of 60° or more, although the direction of dip varies, being about equally distributed between north and south. Four of the prominent N.58°E. joints are continuous from top to bottom of the opening. The more nearly vertical joints not uncommonly pass upward or downward into less steeply dipping joints, with which they unite. In other cases they are offset by and themselves offset the joints of lower dip. The joint surfaces are not uncommonly coated with quartz or calcite; the calcite coats the sides of the joint crevices, the quartz being central; this relation is interpreted as meaning that the quartz was the last mineral deposited (see also Plate XXXI, C, p. 243).

A noteworthy feature is the presence of two cleavage slip planes, one about 20 feet, the other 30 feet below the surface. Both show a white mineral (quartz?) in the zone of the plane. Neither gives absolute evidence of movement and both are crossed by all major joints, though a few less conspicuous fractures stop at these planes.

History and development.—The Chapman Standard quarry was opened in 1860; the first deed recorded carries the name of Charles F. Griffin and is dated 1874. In 1876 Daniel P. Griffin purchased the property. In 1886 the quarry was leased and in 1890 purchased by the Chapman Standard Slate Company of Philadelphia. In 1926 this quarry had been purchased by the Chapman Slate Company.

Three cables with masts and pulleys give access to the opening. An engine house is located near the north corner of the quarry. In 1924 eight shanties were in use. The products include roofing slate and some slate slabs. The roofing slate is classified into "firsts" and "seconds," according to whether the cleavage is rough or smooth, which is generally determined by the presence or absence of thick siliceous "ribbons."

6. CHAPMAN QUARRY.

Location and dimensions.—Two large holes constitute the workings of the Chapman Slate Company, one of the oldest producers of slate in Northampton County. The two openings are almost continuous, but are separated by a wall of rock about 50 feet wide. They lie between and along the strike of the Keystone and Chapman Standard quarries, and roughly 1,200 feet north of the Chapman station. The western opening is the smaller. It is roughly rectangular in areal dimensions, about 450 feet long by 300 feet wide, and 130 feet deep. The eastern opening is irregular in shape, has about the same width, but is 1,000 feet long, and rivals the largest quarries in the Bangor and Pen Argyl districts in volume; its depth is 150 feet.

At present much of each of the openings is filled with waste and water stands in the bottoms of both. Where work is not in progress

waste has accumulated on the working levels, and here and there the walls have collapsed.

A large dump virtually surrounds both excavations, but has been built up mainly on the southeast and northwest sides. Much waste is now being thrown into the east opening.

In 1924 quarrying was in progress at the southwest end of the west hole on two step-like levels beneath the surface, and at the northeast end of the east hole on two similar levels. The bottoms of both quarries are abandoned.

The geology of these two openings cannot here be described in great detail, but the outstanding features may at least be mentioned. A separate description is merited for each opening.

Figure 42. Diagrammatic sketch of folding seen in northeast wall of west opening, Chapman quarry, as viewed from southwest side. Compare with Figure 41.

Geology of the west quarry.—The excavation shows slate under an 8 foot overburden of clay set with slate chips. The beds at the surface strike N.60-70°E., and dip 30°S. in the south corner. Approximately the same strike is preserved throughout the depth of the opening, but the dip reverses itself several times; in fact, parts of the two anticlinal folds that were described in the Chapman Standard quarry are visible in the northeast wall. There is this slight difference in the folds exhibited, however: the greater erosion and the greater depth of bottom in the Chapman quarry caused the surface

to be carried beneath the highest anticline of the Chapman Standard and there is displayed instead an anticlinal axis at the very bottom of the opening, where the beds dip 80°S.

As the planes of these folds strike N.70°E., whereas the greater part of the southeast quarry wall trends N.60°E. along a joint, traces of these folds on the southeast quarry wall give the effect of half-ellipses instead of arcs of circles, such as they really are, and of great flattening and thickening in the troughs and crests (see Plate XXXIII, A) ; however, both these impressions are seen to be incorrect when the northeast wall is viewed along the strike (Figure 42).

The cleavage strikes generally about N.70°E., dips 12-20°S. Grain trends N.41°W., and is vertical.

Joints form many of the smooth faces seen on the quarry walls. The most conspicuous strike N.60-70°E., dip vertically or steeply to the north. Locally these pass downward into joints of lower dip, but more commonly they hold their courses across the more gently dipping joints. One of the vertical joints forms most of the southeast, and another much of the northwest wall, and two others pass completely across the quarry. Minor, compensating joints strike parallel, but dip 33-60°S. These are generally cut by the joints having the steeper dip. The pattern outlined is very closely similar to that seen in the Chapman Standard quarry, where, unfortunately, none of the joints actually measured and plotted belong to the more gently dipping system. Some of the joint planes bear coatings of fibrous calcium carbonate.

The regularity of these jointing systems is well displayed in the photograph, Plate XXXII, B.

Geology of the east quarry.—Although apparently more complex in structure, the geology of the east quarry is similar to that of the west opening and to the Chapman Standard quarry. The anticlinal axes are at depths of 30 and 100 feet. The same fold traces are seen in the southeast wall (Figure 43), as in the corresponding side of the west

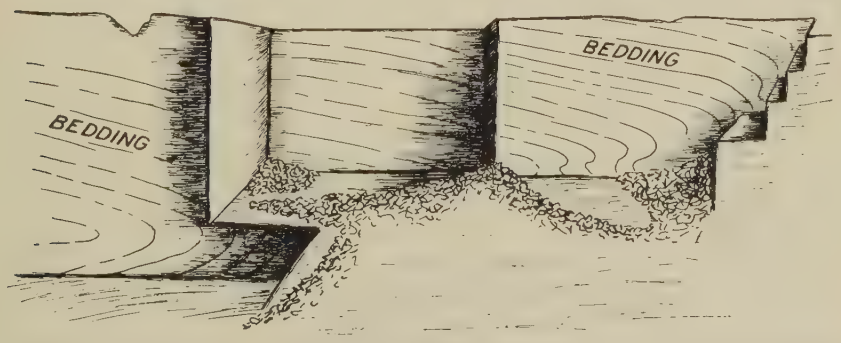


Figure 43. Sketch of folding in southeast wall of east opening, Chapman quarry, as seen from northwest side.

PLATE XXXII

A. Jointing in northeast side of Belfast quarry, looking N. 75° E. from middle of southwest side. Several major joints strike N. 70° E. and dip almost vertically.

B. Southwest wall of west opening of Chapman quarry, as viewed from north corner. To show the influence on quarrying of the strong joints striking N. 65° E. and dipping vertically.

opening, though here not so readily pieced together because of the presence of irregular reentrants in the walls. At the surface on the northeast side of the hole, the beds strike N.70°E., dip 28°S., but about 40 feet below the surface the dip is vertical. The cleavage strikes approximately N.60-65°E., dips 15°S. Grain trends N.40-47°W., and is vertical.

Jointing is well marked. In addition to many lesser, irregularly curving, and generally iron-stained joints, called "scows" by the quarrymen, there is the same system of major joints striking N.55-80° E. and dipping vertically, and a set of fractures that strike N.10°W.-10°E., dipping steeply. An unusual set of four joints strikes N.35°E., dips 75°S. As in the opening to the west, many of the joints are coated with calcite (see also Plate XXXI, p. 243).

A rather unusual feature is the presence of minor faulting parallel with the cleavage and apparently relieving the small folds. This is well shown in some of the rusty beds on an abandoned working level east of the true working level. A small fault, similar to those in the Jackson Bangor quarries and having a displacement of one foot, is seen in the southeast wall of the working level. The plane could not be measured, but it is clear that the beds beneath it moved forward, the fault in this respect again resembling those of the Jackson Bangor openings.

History and development.—The Chapman Slate Company, of Bethlehem, Pa., was organized in March, 1864, by William Chapman, the uncle of the present owner. The firm is controlled by the Chapman family. Production has been continuous since the opening of the quarry in 1850, but was severely reduced during the war, the price of slate being about doubled between 1914 and 1918 because of the cost of labor.

When studied, the north hole was served by three masts and cables, the south by four; all masts are in excellent order and of steel instead of wood. At the west opening one of the cables is fitted with a mast at both ends, to keep it clear of the ground. There are the usual motion shanties and hoist houses. Twenty-one roofing slate shanties were in use in 1924. The arrangement of the tracks is illustrated in Figure 44. An electric locomotive is used for hauling.

The products include all sizes of roofing slate. A feature is the making of especially thick slate upon order; this slate, three-quarters of an inch in thickness, is used to impart a rustic finish to residences designed to resemble old manor houses. The standard sizes of roofing slate produced vary up to 16 by 27 inches, with a thickness of 0.25 inch. Occasional orders are received for heavy flagging for garden walls. Grave vaults and fence posts are also made. About

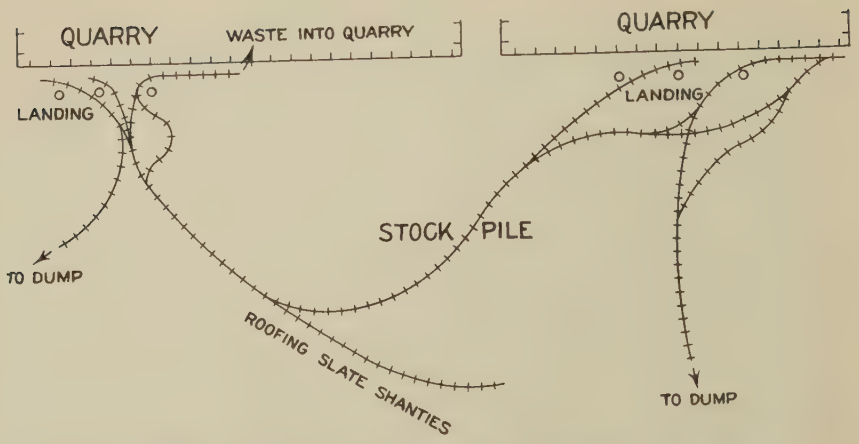


Figure 44. Diagram to show plan of tracks of Chapman Slate Company.

thirty years ago blackboards were produced, polishing being done with the aid of diamond dust.

7. KEYSTONE QUARRY.

This opening is about 2,000 feet north of the station at Chapman and immediately west of the railroad. It is 270 by 325 feet in maximum dimensions and irregular in outline. It is said to be 250 feet deep, but is now filled with water. The slate in the walls is not accessible. A large dump is northwest of the opening, and some waste is also piled up to the east.

The bedding could not be seen from the surface. The cleavage appears to strike N.60°E., and dips 20°S. Several joints were seen striking N.60-70°E., dipping 70-90°W.; three of these form the northwest wall of the opening.

The equipment remaining consists of two hoist houses, two masts, and four cables.

This quarry was opened about 1860. Some time ago it was acquired by the Keystone Slate Company, which operated it until the middle of 1914 and sold the property in 1921. The purchaser was Mr. Jacob Orkin of Easton, Pa.

8. QUARRY.

A small cut in the hillside, about 400 feet N.65°E. from the Keystone quarry and east of the railroad, is 60 by 30 feet in area and has a maximum depth of 30 feet. In the south wall the cleavage strikes N.60-70°E., and dips 13°S. In the walls minor recumbent folds are visible, with axial planes striking N.70°E. and dipping 13°S.

PLATE XXXIII

A. Surface of conspicuous joint striking N. 60° E., on southeast side of west opening, Chapman quarry. To show projections of folds on this surface.

B. Dump and twenty roofing slate shanties of Chapman Slate Company.

9. WAGNER QUARRY.

About due east of the Keystone quarry 1,000 feet, and east of the railroad is the Wagner quarry, a small cut, 30 feet square and probably 25 feet deep. The bedding is not discernible; cleavage strikes N. 70° E., dips 23°S.

This opening was clearly only a prospect.

10.—11. FISHER NOS. 1 AND 2 QUARRIES.

These two quarries are about 300 feet apart. The south opening is 500 feet N.50°E. from the church in the town of Chapman. It is about 35 by 50 feet in size and probably 35 feet deep; 20 feet of slate show above water level in the walls. The beds strike approximately N.65°E., dip 14°N., while the cleavage appears to strike parallel with the beds and dips 15°S. Grain trends N.35°W.

The larger opening is across the stream, northwest from the quarry just described. It is roughly triangular in general form, but has numerous reentrants and projections in the walls. The depth is probably 60 feet, but water rises to within 20 feet of the surface. The beds strike N.75°E., and dip 15°N.; cleavage strikes about due east, dips 11°S. The grain trends N.50°W. Numerous joints are observed, falling into two sets, one striking N.0-15°E., dipping 50°E., the other striking N.65°E., dipping 70°S. These joint systems closely resemble those of the surface and deepest levels of the Chapman quarry.

The two openings were shut down about 1880, the smaller, south quarry being the last abandoned.

12.—13. LILLY NOS. 1 AND 2 QUARRIES.

These two openings are 300 feet apart and in the valley of the east fork of the small stream that flows through the Chapman quarry. Both are small, the northerly being 60 feet square, the other 100 by 25 feet in size. No great depths were reached. The north opening shows no slate above the water, but the southern hole exposes bed rock near the north corner. Here the beds strike N.67°E., dip 37°N.; cleavage strikes N.78°E., dips 10°S. The grain trends N.33°W. Prominent joints strike N.70°E., and are vertical.

The slate produced is typical of the hard belt. That seen on the dump has somewhat fewer "ribbons" than usual, and good cleavage, but bears closely spaced, calcite-filled joints.

These quarries were abandoned in 1875 or earlier. The south quarry was the last worked.

14. FISHER NO. 3 QUARRY.

This small opening lies at the fork of the little creek that flows through the Chapman quarry. It is 50 by 40 feet in size and probably 20 feet deep. Water now fills the quarry. No slate is seen in place. To the south there is a small dump. The quarry was abandoned about 45 years ago.

15. QUARRY.

This old, long abandoned opening is just east of the railroad and ½ mile north of the Chapman station. It is 200 by 30 feet in size

and rectangular. The depth is not known. No slate is seen above the level of the water which fills the hole.

16. MAUCH CHUNK QUARRY.

Directly east of the station at Chapman, on the east side of Monocacy Creek, is a quarry about 250 feet square. This old opening has an extensive dump to the south but no slate is seen in place. Sanders[119] gives the dip as vertical, the cleavage as striking N.50°E., dipping 22°S. At depth the cleavage is said to have been irregular.

Operations ceased before 1880, evidently even before 1878, for Sanders speaks of the quarry as full of water.

17. CHAPMAN SUPERIOR QUARRY.

This moderately large hole lies N.80°E., 5,000 feet from the Chapman quarry and about 3,000 feet N.40°E. from the Siegfried school, in a valley that leads to the east branch of Monocacy Creek. The opening is 150 feet square, and is said to be 125 feet deep. Water now fills it. The beds appear to dip gently north, and the cleavage strikes approximately due east, dips 20°S.

A large dump to the east shows slate much decayed, with closely spaced "ribbons." Two masts still stand on the dump. The quarry was shut down in 1911, according to reports.

18. ED SMITH QUARRY.

The Ed Smith quarry is a small opening, about 40 feet square, 1,200 feet east of the Siegfried school. It is filled with water. A little "ribboned" slate forms a dump on the northeast side, but no rock is seen in place. This is clearly only a prospect hole.

19. HAGENBUSCH QUARRY.

In the valley of the east branch of the Monocacy, about 1½ miles east of the Warren school, is the old Hagenbusch quarry, on the property of Mr. Clinton Hagenbusch of Nazareth, Pa. The hole is 90 by 40 feet in areal dimensions and roughly triangular. Its depth is estimated as 50 feet. No slate shows above the water with which the quarry is filled, but the dump on the southeast side bears blocks of closely "ribboned" hard slate, not heavily rusted nor unduly decayed. Quartz veinlets and a little pyrite are seen in some of the blocks. No machinery remains on the dump.

20. TURNER QUARRY.

The Turner quarry is in the stream bottom, 1,000 feet south of the Reading quarry. It is 60 by 80 feet in size. The depth is not known, but

[119] Sanders, R. H., Op. cit., p. 104, 1883.

is probably at least 60 feet, as a large dump lies south of the opening. A little slate shows above the water, but the bedding is not recognizable; the cleavage strikes N.70°W., dips 15°S.

The slate on the dump is rusted on the "ribbons." The beds are somewhat thicker than is usual in the hard belt.

This opening has been long abandoned. No machinery remains on the dump.

21. READING QUARRY.

The Reading quarry is 600 feet downstream from the Hagenbusch quarry and occupies the southeast angle at a road intersection 1½ miles east of the Chapman quarry. The hole is filled with water to within 20 feet of the bed rock surface. It is estimated to be 60 feet deep. In ground plan it is triangular, the "base" of the "triangle" trending about due east and being 200 feet long, the "altitude" about 150 feet.

In the northeast wall the cleavage strikes N.80°E., dips 30°S.; bedding strikes N.85°W., dips 12°S. The bedding dip in the bottom is said to be close to 30°. The slate on the dump is of good quality.

Several joints striking N.85°E. and vertical are conspicuous in the walls.

This quarry was operated at intervals up to 1893.

22. MAGEE QUARRY.

This is the western of two openings that are immediately northeast of the highway three-quarters of a mile N.60°E. from Dannersville, and half a mile northwest of the Steckel quarries. The Magee quarry measures about 70 by 85 feet and is irregular in outline. The probable depth is 50 feet.

Typical hard slate is exposed. The beds strike N.35°E., dip 28°S. Cleavage strikes N.70°E., dips 15°S. Grain trends N.45°W. Conspicuous vertical joints strike N.75-80°E.

The quarry was opened in 1866 by a Mr. Magee of Easton, with whom were associated others of Easton and Bethlehem. Lease and operations were abandoned in 1872 and the quarry has not been worked since.

The product was roofing slate.

23. RIPPON AND WOLLE QUARRY.

This lies 150 feet east of the Magee quarry and directly across the stream. It is a subcircular hole, about 60 feet in diameter and having a depth of 40 feet. Along the northeast wall, under an overburden of weathered slate, the beds, some of which are here as much as 6 inches thick, curve around the axis of an anticline that was overturned northward; the axis dips 15°S. The cleavage strikes N.75°E., dips 7°S.

The grain trends N.40°W. Two northeast-striking, vertical joints are seen.

On the dump a few old pipes and a boiler remain. The quarry was opened in 1885 by Richard Rippon and Clarence Wolle. Several thousand squares of good slate were produced. The property belongs to Mr. Clarence A. Wolle of Bethlehem.

24. SCHLEGEL QUARRY.

A small opening is on the south side of the road, east of the Schlegel house, and south of the Magee quarry, on the property of Mr. W. H. Schlegel. No slate is seen in place, the pit being filled with water.

25.—26. STECKEL NO. 1 AND NO. 2 QUARRIES.

Immediately east of the road 2 miles northwest from Bath on a small headwater of the Monocacy, are two quarries only 20 feet apart. The northern opening is irregular in shape, with maximum dimensions of 110 by 115 feet. Only about 8 feet of rock are visible above the water which fills the quarry. The dump is between the road and the opening. The slate is typical hard slate. The beds strike N.35°E., dip 57°N., and the cleavage strike is N.55°E., the dip 11°S. The grain trends N.30-37°W.

The southern opening is rectangular and is 100 by 110 feet. Here, beneath a maximum overburden of a foot of weathered slate, the beds strike N.35°E., but dip southeast, apparently being south of an emerging synclinal axis of which the axial plane dips south.

These quarries are on the Steckel estate and have not been operated since 1870, according to Mr. William Smith of Chapman.

27. DICK QUARRY.

The Dick quarry is a small opening about 1½ miles north of Bath, on the road leading to the Steckel quarries (Nos. 25 and 26), and east of the stream. It is about 20 by 30 feet in size and 15 feet deep at most. A little slate shows in the northeast wall.

This prospect was opened about 40 years ago by Charley Dick.

28. QUARRY.

Approximately 1,800 feet south of the station at Chapman, just west of the railroad and in the valley of Monocacy Creek, is an old quarry. It is about 150 by 60 feet in ground plan. The depth is at least 50 feet, but water now fills the opening. A large dump is situated to the south.

Near the north corner "ribboned" hard slate is exposed, the beds striking N.55°E., and dipping 65°S., whereas the cleavage strikes

N.60°E., dips 13°S. Grain trends N.33°W., dips 75°W. The opening is on the upper limb of a northward overturned anticline.

This quarry must have been abandoned at least 50 years ago.

29. RHYMER QUARRY.

This is a prospect, 20 by 30 feet in area and about 15 feet deep, 1¼ miles N.40°W. of the Bath railroad station. It is situated in the bed of Monocacy Creek and is filled with water. In the bottom of the stream nearby the slate strikes N.50°E., dips 60°S., and cleavage strikes N.63°E., dipping 20°S.

This opening was made about 1895.

30. QUARRY.

About 600 feet due north of the Roth quarry, in the valley of a small stream, is a cut about 35 by 35 feet and probably 25 feet deep. The bedding is not recognizable, but the cleavage dips gently south and the grain trends N. 53°W. This opening, abandoned 50 years ago, yielded roofing slate for nearby houses.

31. ROTH QUARRY.

About one mile N.70°W. of the Bath railroad station is a schoolhouse, approached by a road leading westward. Some 800 feet east of this school is a small opening lying south of the road. This is 40 by 15 feet in ground plan, and 25 feet deep to water level at the south end. About 10 feet above the water is a cleavage slip plane, partially filled with quartz and calcite. Good slate probably came from this opening.

Quarrying was begun here by Joseph Roth. Operations ceased about 50 years ago.

32. ACHENBACH QUARRY.

This is located about one mile north of Bath, on the Chapman road. It is a roughly rectangular opening, measuring 70 by 160 feet in ground plan, between the road and Monocacy Creek. Its depth is about 45 feet, but water fills the opening. A dump lies southwest of the quarry.

Along the east side the overburden of clay and slate chips is 7 feet thick. No slate occurs in place above water level.

The slate quarried was of a fair grade, but core drilling revealed "crooked" slate at depths of 13, 38, and 60 feet, the cleavage planes being warped. These observations, made by B. L. Miller, suggest the presence of cleavage slips in the openings, similar to those seen at the Belfast and Edelmans quarries.

The quarry was operated from 1914 until about 1916, producing

roughly 230 squares of roofing slate in 1914, the only year for which figures are available.

The quarry is now abandoned and no machinery remains. It was opened by a Mr. Achenbach of Bath, in partnership with some New York business men.

33. FLEISCHMAN QUARRY.

This small opening, 60 by 40 feet and about 60 feet deep, is on the west bank of the stream, 300 feet west of the Daniels quarry. About 25 feet of slate show on the west side.

The beds appear to strike N.70°E., dip 17°S., but are not clearly shown. The cleavage on the west wall is curved; it strikes N.70°E., dips 8°S. The strata are thus on the north limb of a northward overturned anticline.

The slaty cleavage is exceedingly rough and irregular, and false cleavage, striking parallel with the slaty cleavage and dipping vertically, is seen. The grain trends N.37.W., and is vertical. Several well-marked joints strike N.65-75°E., dip vertically.

This quarry was operated about 1910 by a Mr. Fleischman. On the dump to the east a block and tackle and mast, as well as two shanties, are still to be seen.

34. DANIELS QUARRY.

The Daniels quarry is about ¾ of a mile N.60°E. from the Pen Allen Cement Company plant, between Bath and Nazareth. It measures 70 by 225 feet, the larger dimension extending N.65°E.; 20 feet of slate show above water level and the opening is estimated to be 60 feet deep. The slate chips on the dump have a good ring and do not "rust" heavily. The bedding is not clearly visible, but there is some suggestion of close folding in the walls. The cleavage strikes N.65°E., dips 11°S.

Slate was quarried here in 1878. More recently the quarry has been used as a reservoir by the Dexter Cement Company, which owns the land.

35. BADER QUARRY.

The quarry was on the farm of Mr. Joe Bader, about seven-tenths of a mile south of the Warren school. Only the dump is still to be seen, the quarry being filled. A little slate outcrops along the stream nearby, striking N.80°W., dipping 20°N.; the cleavage strikes N.15° E., dips 15°S. Typical "ribboned" slate is on the dump.

The opening was abandoned in 1900. It was made by a Mr. Soldt and then passed into the hands of the operators of the Ziegenfuss quarry. Upon the acquisition of the property by Mr. Bader, quarrying was discontinued and the hole filled.

36. ROON QUARRY.

The old Roon quarry is 1.3 miles southwest of the Mill Grove school in the stream valley, not far from the tracks of the Nazareth branch of the Lehigh & New England Railroad. The opening is rectangular, measuring 105 by 45 feet, and is probably about 60 feet deep, the upper 10 feet showing above the water which fills the quarry. Waste slate is scattered about the hole.

The typical hard belt slate beds strike N.58°E., dip 4°S., whereas the cleavage strikes N.65°E., dips 15°S. Grain trends N.35°W. Conspicuous vertical joints seen in the south wall strike N.50°E

The opening is on the property of Edward Roon.

37. HAYER QUARRY.

This opening lies 1,500 feet east of that last described. It is virtually rectangular, small, and probably about 70 feet deep. Some 15 feet of slate are visible above water level on the northwest side. There is no overburden. A dump, with a small amount of slate on it, is west of the opening.

The slate exposed is typically "ribboned" hard slate. In the south corner the beds strike N.10°E., dip 37°N., whereas the cleavage strikes N.60°E., dips 18°S., and the grain trends N.38°W. The structure is thus the south limb of a northward overturned anticline pitching westward, or, to put it differently, with the axis swerving as it extends west.

The joints observed strike N.55°E., dip 60°S.

The quarry, according to Mr. Bader, was last operated about 1915, and probably was opened 5 years earlier. The slate has curly cleavage; the material on the dump rings well.

One mast is still standing, as well as a hoist house. The quarry is on the property of Mr. Israel Hayer.

38. QUARRY.

About three-quarters of a mile down the Bushkill from the Center school and about 2.5 miles directly south of Knechts, on the east side of the creek and road, is a large opening in the hard slate. It measures 250 feet N.82°E., by 100 feet N.10°W. Its depth is not known, but a large dump is south of it. No slate shows above the surface, hence no observations could be made as to the structure.

The quarry is within an enclosure built around the transforming station of the Pennsylvania Power and Light Company.

Seemsville Group

SUMMARY.

The quarries of the Seemsville group are opened along Catasauqua Creek, east and south of Seemsville. Slate produced could best be

shipped through Bath and from that town, also, supplies and labor would normally be obtained when the quarries were being operated.

The beds opened are in the lower part of the hard belt, the lowest subdivision of the Martinsburg. The rock is typical hard slate, though in a few of the openings the "ribbons" must have been unusually thick. The quarries are so largely filled with water that structural determinations are difficult, but the usual close folding of thinly bedded slate is in evidence. Bedding and cleavage strikes are generally N.60-70°E., though in some quarries, such as the Miller opening, they assume a northwest direction. Most of the prominent joints have a northeast strike.

Of these openings, the Koch, Ziegenfuss, and Miller quarries represent fairly extensive operations. All have been abandoned for the last 20 years. The products were mainly roofing slate, with smaller values of slabs, fence posts, and grave vaults.

1. KOCH QUARRY.

This large opening, 250 by 100 feet in size, is just north of the road where the latter crosses the fork formed by the union of the two heads of Catasauqua Creek, three-quarters of a mile southeast of Seemsville. The estimated depth is about 100 feet, but the opening is now so full of water that only on the north side, where the wall rises 30 feet above the water level, can slate be studied. Here the bedding strikes N.55-60°E., dips 17°N.; the cleavage is horizontal. Grain trends N.47°W., and is vertical. One joint, striking N.58°E. and dipping 40°S., is in the northwest wall of the opening. Seven other well-marked joint planes are observed to strike N.70-80°E., with dips of 70-90°S.

The beds in which the quarry is cut are probably approximately the same as in the Ziegenfuss quarry (Number 3, below).

The quarry was already abandoned in 1878, at the time of Sanders' survey[120].

2. QUARRY.

On the east bank in the valley of Catasauqua Creek, 1½ miles north of where the stream is crossed by the Weaversville-Howertown pike, is a dump showing typical hard slate. A small hole, apparently a long abandoned quarry, is situated on the west bank of the stream, directly opposite the waste pile mentioned. No slate is visible above water level.

3. ZIEGENFUSS QUARRY.

This irregularly shaped opening is 1,000 feet N.50°E. from the Koch quarry. It is about 120 by 120 feet in maximum dimensions, but the sides are so irregular, with numerous reentrants, that the

[120] Sanders, R. H., Op. cit., p. 107.

shape in ground plan is not describable. The depth is said to be 100 feet, but the opening is largely filled with water. Slate can be seen in the walls on all sides.

The beds are typical hard slate, fairly free of "ribbons." No rusting is seen, nor any quartz or calcite, except as mentioned below. The slate quarried appears to have been of high quality. The bedding is only faintly indicated, and there is a suggestion of a gentle southeast dip, probably on the lower limb of a northward overturned anticline with horizontal axial plane. The strike of the beds is N.30-35°E., and the dip 35-55°S.

Cleavage strikes N.35-75°W., dips 6-10°S., but these observations are poor. It is curved locally, proving its deformation after development. The grain strikes N.38-55°W., and stands vertical. The joints are irregular and in a measure determine the form of the opening.

A striking feature is a quartz stringer which runs in a plane parallel with the cleavage along the entire northeast wall of the opening.

The quarry was operated until about 20 years ago, when it became difficult to obtain laborers. No machinery remains on the dump.

4.—5. QUARRIES.

These two small prospect pits are located on the south bank of the east fork of Catasauqua Creek, about 1,500 feet east of the Ziegenfuss quarry. No bed rock can be seen; a few small chips of hard slate are scattered near the openings.

6. MILLER QUARRY.

This opening is 400 feet south of the road, opposite the Miller No. 2 pit and in the same valley. It is a large opening, trapezoidal in form and with maximum dimensions of 220 and 270 feet. A slight thickness of slate shows in the walls of the quarry, but water conceals the true depth.

The beds in this opening strike N.65°W., dip 35-75°S., the dip increasing southward. The cleavage has a similar strike, dips 15°S. Prominent joints in the east corner strike N.80°E., dip 67°N.

The slate seen on the dump has a good ring, closely spaced "ribbons," and a somewhat sandy texture for the most part. Surfaces of blocks show papery exfoliation.

This is known as the Miller quarry. It was operated last by Mr. Theo. Whitesell of Easton and Belfast, about 25 years ago. It is described by Sanders[121], who speaks of it as being operated at the

[121] Sanders, R. H., Op. cit. p. 106.

time of his visit. At that time it was called the Chester County quarry.

7. MILLER NO. 2 QUARRY.

One mile due south of Dannersville one of the headwaters of Catasauqua Creek is crossed by a northwestward road. About 300 feet north of this road and in the stream valley is situated a small rectangular opening 40 feet long and 30 feet wide, estmated to be 40 feet deep, and with a small dump. The water level rises to the surface.

The slate on the dump and in the quarry walls has very good cleavage, but weathers readily and gives a papery effect, separate thin cleavage flakes rising above the piece as decay sets in, the whole suggesting exfoliation.

This hole was opened about 50 years ago. It yielded some slate that was ground for paint, but the production was never important.

TECHNOLOGY, PRODUCTION, AND HISTORY OF THE QUARRIES.

TECHNOLOGY OF SLATE.

QUARRY PRACTICE.

The technology of slate has been discussed in much detail by Bowles[122]. The practice in the Northampton quarries and mills may be briefly summarized here.

The methods used in the hard and soft belts are nearly identical, and they are described together.

Form of quarries—In Northampton County, the generally steep dip of the beds encourages the opening of deep quarries. This is especially true at Wind Gap and Pen Argyl, for the beds here maintain an almost vertical position. At Bangor the openings have a larger surface area and are not generally carried to as great depth as at Pen Argyl. In the hard belt the quarries are generally shallow in comparison with those in the soft slate.

The greatest depth is attained in the Parsons quarry at Pen Argyl which, in the summer of 1923, was 530 feet deep in the lowest level. The Albion Vein quarry at Pen Argyl is slightly shallower, having a depth of 500 feet in 1923. The North Bangor and Bangor Central quarries, the deepest now being operated at Bangor, both measured, in 1923, 330 feet from surface to lowest level. The quarries of the hard belt are intermediate in depth between those at Bangor and those at Pen Argyl.

The quarrymen designate the several levels from which slate is being taken as "pieces." Most of the quarries, unless irregular in

[122] Bowles, Oliver, The Technology of slate: U. S. Bur. of Mines, Bull. 218, pp. 23-61, 1922.

shape because of unusual joints in the slate, have two opposite sides parallel and trending northwest; these are spoken of as the "sides" of the quarry. The northwestern wall is the "back" and the southeastern the "front" of the opening.

No slate is being mined by underground methods in Northampton County.

Stripping.—As the quarry is extended in any direction horizontally the overburden is removed either by hand, or more commonly, by steam shovel. Not infrequently a track is laid from the shovel to some place farther from the quarry operations, and cable-hauled trams are used to carry away the stripped glacial debris or waste slate. In many places, as in the Jackson Bangor No. 2 quarry, at Pen Argyl, and in the Columbia Bangor, Bangor Washington, and Bangor Union openings, the waste is thrown into a part of the quarry which has been abandoned (See Plate XXI, B). This is wise only if there is no doubt whatever that such abandonment is to be permanent.

Drilling.—Drilling is now carried on almost wholly by machine drill, compressed air being the power employed. Although it expedites quarrying, drilling is likely to shatter the slate somewhat, so that it is customary to drill into the less valuable beds.

Blasting.—In the past, blasting has been resorted to more than now. It is finding less favor as time goes on. Dynamite and hand firing are most usual. Blasting as a general practice has been severely condemned by Bowles[123] because it shatters the slate and breaks it into splintered fragments. The contrast between blasted and channeled walls is shown in Plate XXV, A.

Channeling.—Channeling machines are being substituted for cruder methods in cutting the slate away from the sides of the quarry. The track channeler is now in general use. It shatters the slate for some distance from the channel cut, but is otherwise generally satisfactory.

The use of the channeling machine depends not only on the structure of the slate but also on its resilience or toughness. Quarrymen assert that the slate in the Bangor beds is fractured over a far smaller area adjacent to the channeler than in the Pen Argyl beds, and that in the latter the slate of the Diamond "run" is more heavily shattered than that in the Albion "run."

Drilling and broaching.—In the last two years, Bowles has advocated a return to the older method of drilling and broaching, especially in those quarries where the slate is very brittle or "tender,"

[123] Bowles, Oliver: Op. cit., p. 30.

and where the loss through shattering consequent upon the use of channeling machines is excessive[124].

"For this purpose the drill is mounted on 'quarry bars,' two heavy pipes, one above the other, mounted on a wooden frame. The drill mounting holds the drill exactly vertical and as it may be slid back and forth on the bars, a line of holes 8 to 10 feet in length may be drilled from one position of the bars. The holes are drilled 8 to 10 feet deep and as close together as can be conveniently accomplished without a tendency for the drill to run into the adjacent hole. Cores ¾ to 1 inch wide at the top are usually left between the holes, but the cores are wider at the bottom as the drill loses gage with depth." "In the case of the New Diamond quarry, the cores were 2¾ inches wide. As each hole is completed a wooden plug is driven to keep it free of cuttings. The cores are cut out in a subsequent operation with a broaching tool." This method appears well adapted to the Pen Argyl beds, especially to those above the Albion "run"; in the tough slate of the Bangor beds it seems to be unnecessary. A photograph of a broaching bar is shown in Plate XXXIV, A.

Removing blocks.—Although the methods used in removing slate from the floor of the quarry vary greatly according to the structure of the slate and the predilection of the operators, the general plan may be outlined. Operations first lay bare the cleavage surface that forms the bottom or floor of the opening. In the quarries of Northampton County the floor generally slopes southward at angles not exceeding 25°; rarely it is horizontal.

Slate is now removed from one corner or part of the quarry to furnish a more or less vertical face, the "key" face, by means of which the rest of the slate making up the floor can be attacked. A channeling machine or drilling and broaching device is now used, or a series of holes is drilled and a charge fired so as to break the slate parallel with the grain direction and along the side wall of the quarry. A channel cut is then made approximately at right angles to this line of fracture. Another fracture is induced along the grain, but far enough away from the first to give the desired width to the slab. There is now a well-defined rhombic block, three sides of which are bounded by the fractures described above, and the fourth by the vertical "key" face.

Next, a series of holes is drilled into the "key" face in such a way that all holes lie in the same cleavage plane. A light charge of powder is exploded in these holes, to free the surface slate from that below the holes. A more or less rhomboid block is thus freed.

[124] Bowles, Oliver, Technical progress in slate mining: Eng. and Min. Jour.-Press, vol. 117, pp. 606-7, 1924. More recently experimental work has been carried on by the U. S. Bureau of Mines, looking toward the utilization of a wire saw for cutting quarry blocks.

PLATE XXXIV

A. Broaching bar with mounted drill; New Peerless (Bangor Vein) quarry.

B. Typical waste heap; Keenan Structural Slate Co., Albion quarry, Pen Argyl.

This block is now pried up by several men, who work in unison, using crowbars as levers (see Plate XXXV, A). It is ready for removal from the quarry.

Occasionally an unusually regular system of joints can be utilized so as to obviate the channelling at right angles to the grain. In that case the edges of the block to be removed are bounded by two joints on opposite sides (if conditions are ideal), by two fractures induced along the grain on the remaining sides, and by the cleavage plane below.

Many variations in method are substituted where structural relations of bedding or jointing are suitable.

By further breaking along the grain, cleavage or joint surfaces, the large block of slate may, if necessary, be still more reduced in size until it can be conveniently hoisted out of the quarry.

Hoisting.—In Northampton County all quarries are equipped with steel or wooden masts, which support cables that are thrown across the mouth of the opening and are anchored by heavy guy-ropes on the side opposite the landing. The main cables measure 1.5 to 2.5 inches in diameter, while the draw cables are from a quarter to three-quarters of an inch thick, the cableways being designed to carry from three to five tons, according to Bowles. Carriers are used on the cables and from these a chain is suspended which is directly attached to the large blocks of slate, or, when men or waste pieces are to be hauled, is fastened to a flat box.

Hoisting is carried on by drums mounted in covered engine houses some distance back from the brink of the quarry. Instructions for hoisting are given by the men in the hole, who call or motion to the "signal boy," generally a boy or young man stationed in a small shanty that overhangs the quarry. The "signal boy" then directs the engineer, either by voice or, more commonly, by a system of bell signals.

Great care is taken in hoisting, and close cooperation between the men in the hole, the "signal boy," and the hoist engineer is required.

The arrival of a block of slate on the landing after having been hoisted out of the quarry is shown in Plate XXXVI, A, on which the cable rigging may also be seen.

Transportation from the quarry.—Waste slate removed from the quarry is generally placed on hand cars and hauled to the dump.

Large blocks are marked before removal from the pit, to indicate whether they are to be thrown away, or used for millstock, roofing, or blackboards. Those to be used when unloaded at the landing, are

A. Removing slate from quarry floor with crowbar. Photograph by Bliss, Easton, Pa.

B. Trimming and splitting slate in the roofing slate shanty. The chain that moves the trimming tool is attached to the spring pole above the window. Photograph by Bliss, Easton, Pa.

PLATE XXXVI

A. Arrival of block of slate on landing. Photograph by Bliss, Easton, Pa.

B. Sawing slate on mechanical sawing table. Photograph by Bliss, Easton, Pa.

carefully placed on tram cars and pushed or hauled either to the mill to be finished into structural or electrical slate or into blackboards, or to the small houses, called "shanties", in which roofing slate is made.

SHANTY PRACTICE.

Reduction in size.—Blocks sent from the mill or directly from the landing to the roofing slate shanties must be reduced to dimensions adapted to ready handling. The saw used for this purpose is generally 36 inches or more in diameter, and is about three-eights of an inch thick; the teeth are fixed in one piece with the blade. The saw turns slowly around a horizontal axis, making between five and ten revolutions per minute. While it rotates the iron table on which the slate rests moves forward at a slow rate. As the table is slotted, and the saw is directed to follow the slot, the slate is gradually forced against the teeth of the saw, which cuts it, according to Bowles, at the rate of three to twenty inches per minute. To prevent the slate block from being pushed back on the table as the saw advances against it, plugs are driven around the piece into the holes of the grating that forms the table. If necessary, the block is thinned after sawing by splitting it with wedges set parallel with the cleavage.

Splitting.—When the slate has been reduced to pieces about 1.5 x 2 feet in area and 5 inches or less in thickness, it is carried into the small sheds or shanties.* Here the splitters swab the blocks with water. A thin, wide-bladed, and very flexible chisel is then worked into the slate along cleavage cracks by gentle tapping with a mallet. When the chisel is finally well inserted another is commonly entered in like manner, prying apart the same two cleavage surfaces. Gentle tapping and deeper forcing of the chisels finally induces the slate to part along the desired plane (see Plate XXXV, B).

In some quarries, notably in the hard belt, one or two saws are set up near the shanties to cut up only such slate as is intended for roofing. In quarries where mills are operated, however, the smaller pieces cut from the large blocks that were destined for structural purposes are also utilized and these of course, require no sawing but are sent directly to the shanty.

Trimming.—After the rock is split to the thickness of roofing slate, it is trimmed under a heavy steel blade which is fixed at one end and is operated by a treadle. The blade is made to swing by a spring pole, placed outside the shanty. This instrument cuts the larger pieces of thinly split slate into the sizes desired for roofing.

In general a piece of slate is cut out to the largest size possible consonant with the standard roofing sizes. A set of metal plates attached to the trimming machine is so arranged as to permit the rapid gauging of the dimensions to which the slate piece is best adapted. It is said that the treadle must be worked more slowly for more brittle and softer slate.

* Recently the Jackson Bangor Company has done away with its shanties and substituted one large building to house all splitting operations. See footnote, page 219.

This method of trimming slate is in practice in both soft and hard belts in Northampton County. Attempts have been made to introduce mechanical trimmers, but without success.

Punching.—On demand some producers still punch the slate, making the nail holes. This is done with a mechanical punching machine, operated by a treadle. Opinions differ among operators as to the desirability of punching slate before shipment. Some assert that the loss suffered by the operators in punching slate is appreciable. Others say that service is better if punching is done at the quarry because the full quantity of slate ordered is then available to the consumer, no losses being sustained by him after receipt of the shipment; this, they believe, begets better feeling between producer and consumer and more than balances the slight financial loss of the quarrymen due to breakage of an occasional slate in punching.

Punched slate costs more than unpunched slate. The punchers are payed by the number of slate punched.

Storage.—Roofing slates are stored outdoors in the Bangor quarries and in the hard belt, but in the Pen Argyl district it is preferred to keep them covered. When exposed to the weather the soft slate becomes slightly lighter in color and some producers prefer to have such changes take place at once. Hard slate undergoes no visible color change with exposure.

Waste disposal.—The chips from the shanties are commonly thrown out of a chute conveniently placed near the trimming machine. A huge pile of waste slate is thus built up, necessitating periodic moving of the shanties. This accumulated waste is a striking feature in the slate district. The photograph in Plate XXXIV, B, emphasizes its extent. For a further discussion of this subject see the section under Waste.

MILL PRACTICE.

Hard and soft belt methods compared.—In the hard belt the milling is a very simple process, the only products besides roofing slate being grave vaults, fence posts, and rough slabs of various sorts. No elaborate mill machinery is necessary and the mill practice consists merely of sawing the slate into specified sizes and then splitting it to the desired thickness. The saws and chisels used are similar to those described above under shanty practice. Splitting methods employed resemble those employed for roofing slate. In the soft belt the process is more elaborate. A brief description follows.

Sorting.—Either before entering the mill or at the entry way the slate blocks are graded, so that it is known whether they are intended for blackboards, for structural slate, or for electrical purposes. In sorting, slate is designated as (1) "clear stock," if consisting of only light gray or greenish gray slate, free from carbonaceous bands ("ribbons") or siliceous layers, or (2) "ribboned" slate, if the block bears

carbonaceous or siliceous beds. Unusually thick beds of clear stock are set aside for blackboards. Pieces from certain beds which, through test or use, are known to yield good electrical material are saved for switchboards and insulation.

Mill building and plan.—Slate machinery is generally housed in a wooden shed, the mill or factory, which is longer than wide. An aisle is left open down the middle of the building and parallel with the length. In many mills tracks are laid in the aisle, and a small hand car is utilized to transport the rough slate blocks or finished products.

The various pieces of machinery are arranged on either side of the middle aisle, in such a way as to facilitate as direct transportation from machine to machine as possible. The mill plans vary with the machinery used, the kinds of slate products made, and the views of the operators as to the best arrangement of the machines. Several mill plans are presented in the detailed quarry descriptions. Bowles has discussed the matter of mill planning in much detail[125].

Mill transportation.—Four methods of handling raw and finished slate in the mill are utilized in Northampton County. These are, by boom, hand car, horse-power, and crane.

Many slate mills are equipped with a block and tackle attached to a rotating boom. Such an appliance is used outside the mill shed for moving blocks from the hand car to the saw tables, or within the building to shift pieces from one machine to another, the length of the horizontal arm of the boom being the measure of its working radius. In some mills the block and tackle can be moved along the length of the horizontal arm. In one mill a chain and grapple are mounted on an S-shaped track; this appliance is used for moving slate from saw table to planer.

Much transportation is effected by hand-pushed or horse-drawn cars, moving on a track which is laid along the middle aisle of the mill.

In four mills in the district, overhead cranes, travelling on tracks attached to the roof, are installed. The five-ton Shepard crane appears to find most favor. The initial expense is a deterrent, but the crane certainly expedites the handling of waste and of larger blocks and so probably pays for itself in a short time.

Power.—Steam, gasoline, and electricity are all utilized for power in the Northampton County slate district. Steam power and electricity vie with each other for use in driving mill machinery and air compressors. Steam is generally used for hoisting. Gasoline is preferred for pumps and quarry machinery.

The electricity is largely furnished by the power companies over transmission lines which follow the southern flank of Blue Mountain.

[125] Bowles, Oliver, The technology of slate: U. S. Bur. of Mines, Bull. 218, pp. 77-80, 1922.

These lines are shown on the areal geology sheet.* Transformers are a necessary part of the power equipment.

Anthracite is the usual fuel. The boiler house is a separate building placed, as a rule, some distance from the mill.

In the mill the machinery is generally linked to one or two shafts which parallel the length of the building. Generally one of these is a drive shaft and is belted to the other.

Reduction in size.—This process is similar to that already described in the case of shanty operations. Two sizes of saws are commonly used, one measuring up to 4 feet in diameter ("buck-saw") for the preliminary reduction of the rough blocks, and another ("rip-saw") generally having a diameter of about 2 feet, for removing irregular edges or for cutting partly finished or thinner slabs. In some mills a large saw of the former type is mounted outside the mill shed. Within the shed the larger saws are generally placed near the entry, the smaller ones being closer to the planers and other machinery.

Plate XXXVI, B, shows a rough block of slate, mounted on a sawing table, being cut into pieces of usable size.

Planing.—The slate is next planed to a smooth surface. For this purpose the block is placed on a bed which travels back and forth as does a sawing table. The motion carries the slate under a blade which is set at a very low angle to the horizontal. As the blade is not as wide as the bed on which the slate rests, and hence also generally not as wide as most slate slabs, it must be moved laterally from time to time to bring it in contact with the entire surface. Further the blade is mounted in a geared rack, so that it may be progressively lowered to cut the slate into thinner slabs. Needless to say, such machines require skilled operators, as it is desired to make the surface absolutely plane (see Plate XXXVII, A).

Sand polishing.—For much structural material the planed surface is sufficiently even, but in many cases, notably in the manufacture of blackboards, a yet smoother finish is desired. For this purpose, as well as for perfecting the edges of other pieces of which the large surfaces do not require a polish, a rubbing bed like that shown in Plate XXXVII, B, is used. This consists of a disk of iron, 12 feet in diameter, rotating around a vertical axis. Sand is placed upon this as an abrasive and a stream of water is directed upon it. Downward pressure is exerted by weights placed upon the slate as it lies upon the rubbing bed.

Buffing.—To give a final polish a buffing machine is used on the slate. This is necessary only in the case of blackboards, bulletin boards, and switchboards.

* In 1926 a new transmission line, not shown on Plate II, connected power lines to the south with the Chapman quarries.

PLATE XXXVII

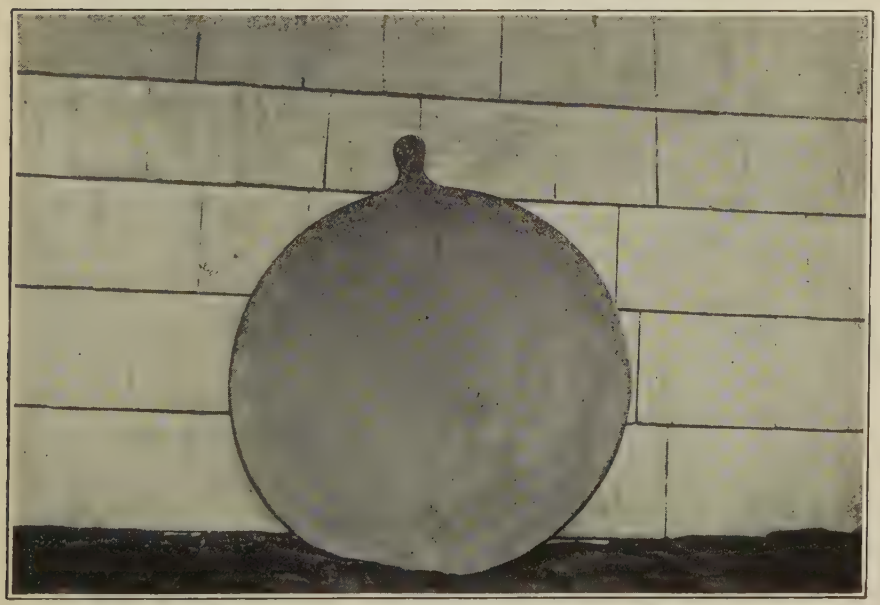
A. Planing machine in operation. (Photograph by Bliss, Easton, Pa.)

B. Rubbing bed. A slate slab is seen resting on the disk-shaped rubbing surface and another is held by the operator with its edge against the surface of the rubbing disk. (Photograph by Bliss, Easton, Pa.)

Buffing machines are of two types. One of these, the Vermont type, consists of a disk-shaped head in which are mounted b'ocks of abrasive material. This polishing head is rotated by a belt connected with a power-driven shaft and is attached to a movable vertical arm. Pressure of buffer against slate surface is supplied by a heavy spring, upon which the operator exerts traction. Water is directed upon the slate while the polishing is in progress. This type of buffer requires careful operation and finishes only a small area at a time.

The other type of buffer has several arms or rods (generally six), each carrying a polishing block. When smaller pieces are polished not all six arms are needed but in such cases those not in use are generally left in gear. The arms rotate around vertical axes so that each polishing block acts on a circular area. From time to time the

PLATE XXXVIII

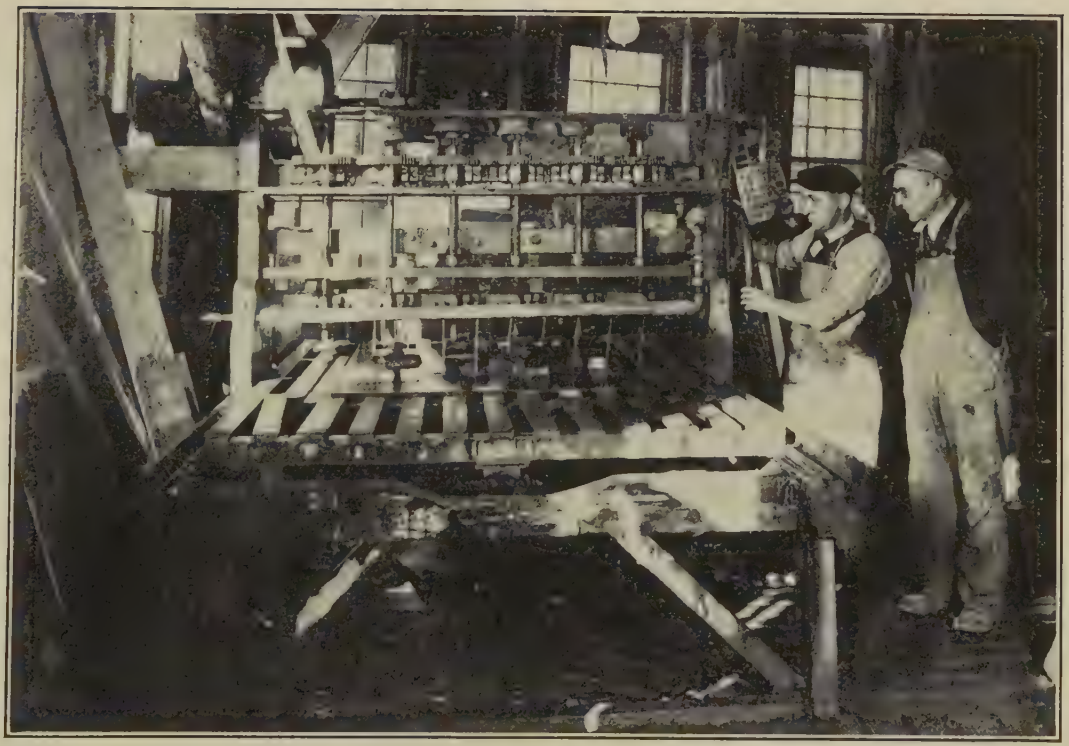


Bread-board of soft slate. Diameter 24 inches.

slab is moved until it has all been gone over in this way. Such a buffer is shown in Plate XXXIX.

Carborundum wheels.—These are employed in many mills for bevelling and for cutting small slabs of slate to the desired size. They are coming into increasing use. In some instances they are placed on travelling axles, so that the slate can be fixed and the wheel forced against it mechanically.

Shaping and drilling.—As a final stage in bevelling, shaping, groov-



Multiple-head buffing machine. Four abrasive heads are being used. (Photograph by Bliss, Easton, Pa.)

ing, or fitting slate for switchboards or for tubs, sinks, and troughs, hand work is resorted to. Perhaps the greatest skill in the slate industry is needed for these finishing steps. In many mills drilling for wiring or bolting is also done by hand, but some factories use mechanical drills, which are, in cases, multiple, so as to permit the drilling of several holes at once.

Electrical slate testing.—By empirical methods the beds capable of yielding electrical slate are known. The outstanding characteristics of these beds are their uniformity of grain and the absence of magnetite and pyrite, of excessive graphite, and of small areas bearing more than normal quantities of silica. Although most of these undesirable features can be easily recognized upon superficial inspection, they are frequently not seen when present, especially if the slab is thick and conceals them in its interior. For testing the electric insulation of slate, a special apparatus consisting of a transformer, milliameter, and wires with brush-like terminals has been devised by Robert Notvest, working for the Structural Slate Company.[126]

A wire is applied to one side of the slab, and with the other wire all points on the slate surface are brushed over to see whether there is any leakage. This is determined by the flow of current recorded on the milliameter.

Blackboard making.—Blackboards are split like roofing slate, but more care must be exercised because the slabs are generally larger. They are then sand-rubbed on the rubbing bed, polished under the buffer, and stored in a separate shed. In one factory the old practice of hand planing the slate for blackboards is still followed. For this purpose a sharp blade with long cutting edge is used. Blackboards must be carefully crated for shipping.

School slate.—This is made from beds darker than the usual light-gray slate, but not as dark as the "ribbon" or highly carbonaceous layers. The slate is split, like roofing slate, and then trimmed with a rapidly rotating saw shaped like a square with a triangular prolongation at each corner. The sizes of school slates vary from 4 x 6 inches to 9 x 13 inches.

A small school slate factory operated by the Griffin Brothers is located at Flicksville. The school slate that has been split and trimmed at the North Bangor quarry is brought here for finishing.

Each piece of slate is first sent through a beveller; this bears a carriage by which the slate is propelled over knives which have their blades inclined in such a way that one edge of the slate is bevelled in transit.

When the piece has been bevelled on all edges, it is forced between

[126] Slate for electrical purposes: The Structural Slate Co., Pen Argyl, Pa., pp. 33-34, 1923.

two knives placed with their blades only far enough apart to permit the passage of the desired thickness of slate (1/6, 1/7, and 1/8 inch, according to the grade specified). This machine is called the shaver.

For final surfacing the bevelled and shaved slate is passed between two paper covered cylinders which rotate rapidly in opposite directions; this machine acts as a buffer.

School slate destined for domestic use is framed here as well, and a bit of colored goods is applied to the outside of the frame. The finished slate is carefully packed in boxes. Much of it is prepared for export, especially to Europe.

Accessory machinery and sheds.—Well equipped slate mills generally have an emery or carborundum wheel for sharpening saws and planer knives.

A separate room is ordinarily supplied for fitting work, such as hand turning and bevelling mill products. Similarly the corps of workers splitting blackboards is commonly given its own workshop, distinct from the rest of the mill.

In many mills there is a lumber shed, equipped with a buzz-saw. Here slate can be crated for shipping.

Adjacent to the mill near the rubbing beds there is a sand house, with a chute leading into the interior of the factory.

Storage.—It is desirable to store most of the finely finished products under a roof. Stock rooms are accessory buildings placed near the mill and connected with it by rail. A separate space fitted with special racks is set aside for blackboard storage.

PULVERIZING MILLS.

Two plants for pulverizing slate have been installed, one at Pen Argyl at the Parsons quarry, the other at Bangor near the Bangor Central quarry. A description of the Pen Argyl plant is given by Bowles.[127] These pulverizing mills suggest a way of utilizing much material that would otherwise be discarded as waste from the slate mills and shanties. The pulverized product is used as a filler in paints, paper, linoleum and rubber.

Lately pulverized slate has found some use in the waterproofing of concrete products. Here too it plays the part of a filler and is inserted to reduce porosity. For this purpose finely pulverized sizes are used in quantities varying up to 20 per cent of the mix, the optimum results being obtained with 12 per cent of the filler.[128]

MARBLEIZING PLANTS.

Marbleized slate is slate in slabs, the surfaces of which have been artifically colored to simulate marble, onyx, or other decorative stones,

[127] Bowles, Oliver, The technology of slate: U. S. Bur. of Mines, Bull. 218, p. 114, 1922.

[128] Anonym., Slate flour used for waterproofing concrete products: Rock Products, Vol. XXVIII, No. 4, p. 77, 1925; quotes from Contract Journal, England.

or clear-grained woods. In former years marbleized slate was much in fashion and was used for mantels, wainscoting, table tops, tiles, and door plates. Checker boards are made, on which the squares are alternately black and highly colored. Colored black, marbleized slate is used for base plates in X-ray apparatus.

The process of marbleizing slate, as practiced by the Butler Brothers Company at Pen Argyl is to apply with a brush a ground coat of color on finished structural slate. The desired pigments in oil are dropped on the surface of water in a vat. The film of color thus formed is broken by agitation. Next the slate slab with its ground color coat is gently lowered, face down, upon the network of paint floating on the surface of the water. This network adheres to the face of the slab when it is withdrawn. Thus the appearance is simulated, for example, of a piece of verde antique. The slate is then finished by heating in a kiln, varnishing, and polishing with pumice.

The Structural Slate Company at Pen Argyl is marketing slabs of slate that are lacquered on one or both sides in various colors, with or without pattern. The lacquer is applied with compressed air and is air-dried. An imitation of black marble with gold veining is also produced. This lacquered slate is called Struco slate, and is used for wainscoting, toilet partitions, table tops, lamp bases, etc.

WASTE.

Utilization.—The waste incidental to slate quarrying is enormous; it has been variously estimated at 60-85 per cent[129] or even more of all the slate taken from the ground. In fact, the reduction and utilization of waste is the greatest problem faced by the industry. The loss is largely inevitable, being due partly to irregularities in cleavage, jointing or some other structural feature, partly to sedimentary factors, such as "ribbons" and "hard rolls." Much of the loss can be assigned to poor quarry and mill practice. This matter has been extensively discussed by Bowles[130], who also suggests various methods of utilizing the slate hitherto thrown away. He mentions the following products in which waste slate can be used successfully:

1. Inlaid slate roofs.
2. Flagging.
3. Fence posts.
4. Wall rock (for placing in the walls of buildings as heat insulators).
5. Rubber filler.
6. Linoleum, oilcloth, and window shade filler (except where these must be white).
7. Filler in plastic roofing and flooring.
8. Bonded briquets for road laying.
9. Filler in sheet surface mixtures in road asphalting.
10. Brick and tile.
11. Synthetic slate.
12. Filler in metal polish.
13. Abrasive soap.
14. Filler in wrapping paper and cardboard.
15. Foundry sand mixtures.
16. Granules for synthetic roofing.

[129] Bowles, Oliver: Op. cit., p. 83; Ries, Heinrich, Economic Geology, p. 112, 1916; Merrill, G. P., Stones for building and decoration, p. 359, 1897.
[130] Bowles, Oliver, Op. cit., pp. 82-107.

Several other possible uses, such as inlaid slate, slate lathing, and slate-surfaced shingles have also been suggested. In several places in the slate district, slate blocks are actually substituted for the wood or brick in the walls of houses. The schoolhouse at Chapman illustrates this use.

Disposal.—The matter of waste disposal has already been touched upon under quarry and shanty practice. It suffices to say that waste accumulates in quarry, shanty, and mill. This waste is disposed of as follows:

1. Waste from quarry operations is dumped at the end of an incline leading away from the quarry or is thrown back into those parts of the opening which have been abandoned.
2. Waste from roofing slate making is dropped beside the shanties, the trimmer in each shanty simply throwing it out through the chute provided for that purpose.
3. Waste from the mill is disposed of like that from the quarry.

Generally the dump on which the larger blocks of waste from the quarry and the mill are thrown is in the form of an incline up which small cars bearing the material to be discarded are either pushed by hand or hauled by horse or cable.

SPECIFICATIONS FOR AND DESCRIPTION OF PRODUCTS.

ROOFING SLATE.

The following sizes and specifications are cited from the standard price list of the largest roofing slate distributing company in Pennsylvania. They apply wholly to soft belt slates:

Standard sizes for roofing slate.

Inches.	Number per square.	Exposure* Inches.	Nails to Square (3-d). Lbs.	Oz.	Inches.	Number per square	Exposure* Inches.	Nails to Square (3-d). Lbs.	Oz.
24 x 14	98	10½	1	0	16 x 9	246	6½	2	7
24 x 12	114	10½	1	2	16 x 8	277	6½	2	12
22 x 14	108	9½	1	3	14 x 14	187	5½	1	13
22 x 11	126	9½	1	4	14 x 12	218	5½	2	3
22 x 11	138	9½	1	6	14 x 10	262	5½	2	9
20 x 12	141	8½	1	8	14 x 9	290	5½	2	14
20 x 11	154	8½	1	6	14 x 8	327	5½	3	3
20 x 10	169	8½	1	11	14 x 7	374	5½	3	11
18 x 12	160	7½	1	9	12 x 12	266	4½	2	9
18 x 11	174	7½	1	11	12 x 10	320	4½	3	2
18 x 10	192	7½	1	14	12 x 9	356	4½	3	8
18 x 9	213	7½	2	1	12 x 8	400	4½	3	15
16 x 12	185	6½	1	13	12 x 7	457	4½	4	8
16 x 10	221	6½	2	3	12 x 6	533	4½	5	4

*Exposure when laid and spacing of lath.

Slate for roofing is sold by a unit called the square, the slate necessary to cover 100 square feet with a 3-inch overlap. The standard thickness is 3/16 inch. Thicker slates are supplied on demand. The weight per square of Northampton County soft belt slates is 650 to 700 pounds.

All Northampton County roofing slate is blue-gray in color; it becomes slightly lighter on long exposure. If the slate is of the sandy ends of beds, there is a tendency to "rust," that is, turn brownish, but such beds are only used in roofing when especially called for, the purpose in that case being to lend a rustic or antique appearance.

The surface of a roofing slate parallels the cleavage. In some quarries cleavage is locally curved; this results in curved slates, which can be used if carefully laid. In imitating old structures, architects occasionally demand such curved cleavage, but for ordinary use it is less desirable than perfectly plane cleavage.

The following specifications are to be looked for under the trade terms when soft belt roofing slates are purchased:

> No. 1 Clear: Tolerably uniform as to surface; thickness about 3/16 inch; straight, with clean corners; entirely free of ribbons.
>
> Semi-Clear: Same as "No. 1 Clear," but may have ribbons which in this case lie above the nail holes and hence are hidden by the overlap.
>
> No. 1 Ribbon: Similar in quality and appearance on the roof to "Clear" and "Semi-clear" grades, the only difference being that some of the ribbons come below the nail holes.

In addition most quarries supply a lower grade, called largely "No. 2 Ribbon," which shows ribbons below the nail holes and below the overlap; when such slate is laid on a roof the ribbons may be visible; hence it is more commonly used for roofing barns and sheds. "No. 2 Clear" slate is such as has been culled from "No. 1 Clear" because of curved cleavage, chipped corners, or thickness in excess of the standard 3/16 inch.

In the hard belt no ribbonless slates are produced, but the ribbons are generally not conspicuous after appreciable weathering. These slates are classed as No. 1 and No. 2 on the basis of the smoothness of the surface; highly siliceous ribbons generally warp such a surface slightly and make a No. 2 slate.

The sizes of the hard belt slates are similar to those of the soft belt.

Architects are calling for rough slates, broken slates, slates of exceptional thickness, and slates made from the "hard rolls" (sandy portions) of beds, but these special orders have not been standardized.

ELECTRICAL SLATE.

The following is a digest of the specifications suggested by the largest electrical slate producer in the State:

1. The slate should be clear stock, uniform in color, free from veins, spots, and cracks; specific gravity about 2.8. Absorption of water by weight in 24 hours should not exceed 0.3 per cent. Tensile strength 3500 lbs. per square inch. Modulus of elasticity 8,000,000 lbs. per square inch. Toughness 12 (method advocated by the American Society for Testing Materials). Coefficient of expansion 0.000002° C. or equivalent. Heat resistance to withstand 200° C. without cracking.

2. Slate should not be used for electrical purposes until three months after quarrying.

3. Faces and edges of panels must be true surfaces, accurately cut to dimensions and varying not over 1/16 inch. Adjoining edges shall not deviate from a right angle by more than 1/32 inch. Bevels shall be cut true entirely around panels; they shall be measured by the projected width and depth. Back of panels shall be free from lumps or depressions, but need not be trued.

4. All slate shall be electrically tested prior to shipment with one of several specified devices, and impedence leakage actually measured.

5. Holes drilled in the slate for securing or fastening it shall be 15-20 per cent larger in diameter than the screws, bolts, and other appliances used. Compressible washers shall be used between the slate and the framework.

6. Large slabs four square feet or over in area shall be so supported that the fastening screws or other appliances shall not bear the weight of the slate; large switchboard assemblies shall rest on a substantial iron base, preferably cushioned.

Special devices for testing the impedence and ohmic resistance of slate have been prepared by Mr. Robert Notvest, acting for the Structural Slate Company.

Leakage appears to be due generally either to the presence of free carbon, or of iron compounds (probably mainly magnetite and pyrite), or of water in the slate. Slate to be used for electrical purposes must thus be free of "ribbons" and of larger quantities of magnetite and pyrite (as in veinlets), and it should be dried of its quarry water. There appears to be no objection to silica in electrical slate when it is uniformly distributed and not localized in veins or beds.

STRUCTURAL AND SANITARY SLATE.

For structural and sanitary use, slate should be soft, evenly grained, and preferably not too heavily ribboned. The slate is taken out of

the factory in four finishes,—sand rubbed, honed, and, when polished, in "black enamel" and "white enamel" finishes. It may also be marbleized by a special process.

Less finished and less expensive surfaces are the following, which can generally be supplied on demand:

Sawed edges: This surface consists of concentric groovings, as left by the hack-saw; such surfaces may be used in copings and nosings, —generally outdoor finishes.

Split-face surface: This is rough to appearance and touch; it is the finish left on roofing slate. It is in demand for outside flagging, steps, and walks.

Planed surface: This is smoother than the split-face surface, having no minor roughnesses that can be felt, but the parallel marks of the planing knife can be faintly seen.

It should here be stated that although clear stock may be used for structural purposes, ribboned slate is said to be equally satisfactory in its wearing qualities and is more readily obtainable. It is less costly as approximately 80 per cent of the slate from quarries bears ribbons.

As among the structural and sanitary uses to which slate may be converted, the following may be mentioned: toilet appliances, shower stalls, sinks, tubs, vats, shelving, copings, hearths, stairs, tables, and lithographic stone.

GRAVE VAULTS AND BILLIARD TABLE TOPS.

For grave vaults, the specifications and trade practice in the soft belt are similar to those applied to structural and sanitary slate. In the hard belt the finish is like that described under "Split-face surface" (see "Structural and Sanitary Slate" above), as no milling is given the hard belt structural slate.

The qualifications for billiard table tops are simply that the slate be obtained in large slabs free from joints and veins, that it be soft, and able to take a smooth polish.

SCHOOL SLATES.

For school slate use, slate should be dark and free from knots and ribbons. These slates occur commonly in smaller beds. The beds in the soft belt of that section of Northampton County here described are generally less well adapted to this type of product than those at Slatington. However, at least one quarry yields appreciable quantities of school slate.

BLACKBOARDS AND BULLETIN BOARDS.

Slate for blackboards and bulletin boards should be free from ribbons, of fairly dark gray color, soft, highly fissile, and preferably with plane cleavage. If the cleavage is gently curved, which is not

infrequently the case, the boards may be "sprung" into position because of the elasticity of the slate, and are then as satisfactory as though the cleavage were wholly plane. The sizes of blackboards vary, but standard sizes are 3 feet, 3 feet 6 inches, and 4 feet in width and 4 feet 6 inches or less long, with thickness of ¼ inch to ⅜ inch.

GRANULES

Slate granules, with pulverized slate and similar ground products, depend for specifications wholly on the use to which they are to be put.

HISTORY OF THE SLATE INDUSTRY.

DEVELOPMENT IN THE UNITED STATES.

The history of the slate industry recapitulates the development of most other American business enterprises, in that it passed from small pits with "cut throat competition" to larger scale quarrying with greater cooperation and coordination. The earlier production hoped to enter mainly the roofing market, and toward the middle of the last century it was expected to compete in price with shingles. Rates like those incidental to such a theory proved ruinous and bankruptcies thinned the ranks of the producers.

This depression did not long continue, however. The growth of extensive consumption of millstock in the eighties helped the producers considerably, as it represented a suitable outlet for much of what had hitherto been regarded as waste. Another alleviation of the stress to which the quarrymen had been subjected was the vast improvement of quarrying and milling machinery. Almost all of the larger quarries in the region show along their walls a marked change somewhere in the descent; whereas the upper parts of the quarry faces are rough and very irregular, the lower portions are smooth and cut into step-like parallel benches by the use of channeling machines. These lower sections, then, where the slate was not shattered by excessive blasting as higher up, bear witness to one of the modern refinements of quarry craft that has greatly reduced wastage and cost of operations. Channeling was first practiced in Vermont in 1863 [131] but was probably not introduced into the slate region of Pennsylvania until about two decades later. In the early 90's, also, slate blackboards came into use for the first time and soon furnished another line of product.

The effect of these various beneficial factors was to ameliorate somewhat the lot of the slate producers, and quarries began once more on a promising scale. It is to this later period, mainly, that the growth of the centers of slate industry, such as Bangor and Pen Argyl, are to be attributed. But the appearance on the market of paper, asbestos, and tar roofing materials shortly before the peak production of 1903 was

[131] Merrill, G. P., Stones for building and decoration, p. 404, New York, John Wiley and Sons, 1910.

again the signal for beginning a decline in the slate industry. Concomitantly the school slate consumption suffered greatly at the hands of the sanitary experts of our public schools. This depression marked the commencement of violent competition between the slate men themselves. Several attempts were made to stop such an intense price war as followed; none were successful.

There resulted, then, a marked decline in slate production. Labor costs had risen. Some of the old markets for slate products were on the wane with no possibility of any recuperation in the future; others were being invaded by substitute materials. Freight rates were prohibitive for distance shipments. Added to this, cost accounting was not recognized as furnishing a basis for proper sales prices; expenses were incurred in quarry operations, while prices were cut in a manner wholly unjustified by the small return on the investment. Came the greatest of all catastrophies to the industry, the World War. With the entry of the United States, slate quarrying was almost totally abandoned as an unessential industry. Immediately after our entry into the war the organization of the slate industry, so long projected and so long prevented by internal strife, took place to a considerable degree, and there were formed two larger companies, one to deal with structural products, the other with roofing slate.

The industry is apparently again able to anticipate better days. General slate production in 1923 has risen over that of any year since 1917 (see Fig. 45). Several quarries, hitherto abandoned, are being reopened. Although there was a general industrial decline in 1921, slate suffered less than other commodities and roofing slate produced in 1923 experienced a sales increase over all years since 1917. Electrical slate has become an important factor in the development of the industry. The tendency to standardize specifications is noticeable now. All in all, it seems as though slate were gradually regaining the industrial strength it possessed in 1903, the peak year.

DEVELOPMENT IN NORTHAMPTON COUNTY.

Of Pennsylvania slate districts there are three, (1) that which borders on Maryland at the south, lying in Lancaster and York Counties (see Figure I), and is a portion of the Peach Bottom district; (2) that centering around Slatington and Danielsville, the greater part of which lies in Lehigh County; and (3) that described in this report, which lies wholly in Northampton County and centers about Pen Argyl and Bangor, with other quarries to the south, near Bath and Nazareth. This last is here under discussion, but the figures in the ensuing tables partly include small productions from one or two quarries that lie in Northampton County but ship their products to Slatington, hence should properly be classed with the quarries of the Slatington district.

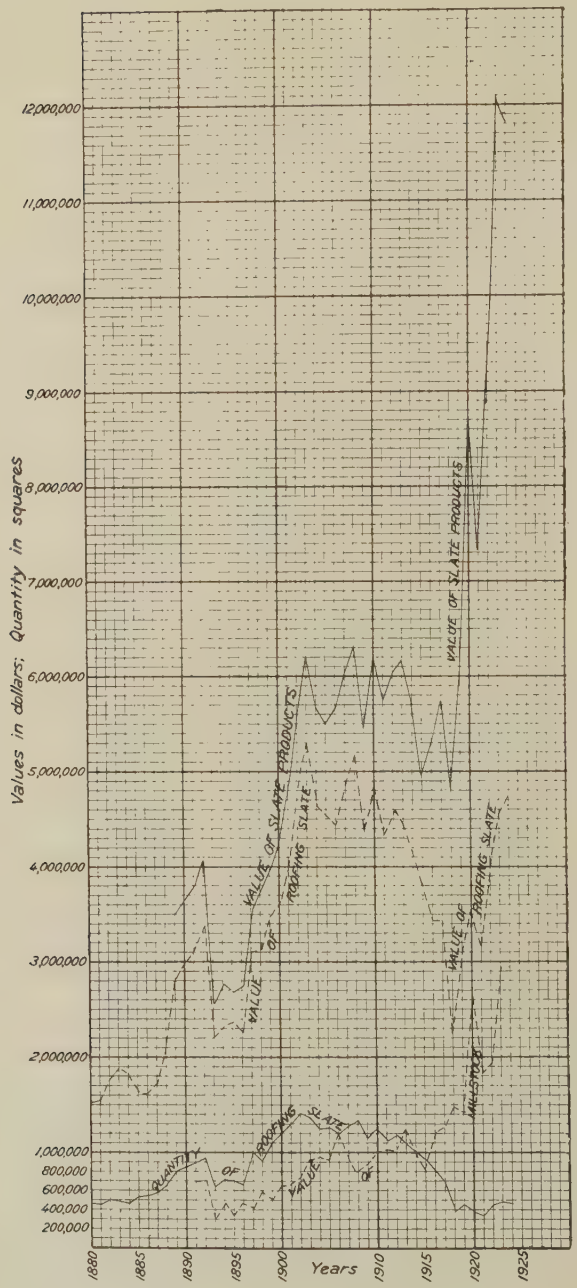


Figure 45. Slate production in the United States.

It may be recalled, therefore, in studying the curves and tables which follow, that the production centering around Bangor and Pen Argyl and coming from quarries lying within the area here mapped is slightly less than that of Northampton County as a whole. In the discussion, also, the historic development of such towns as Danielsville and Walnutport, which really are economically a part of the Slatington District, will be omitted, though these towns lie in Northampton County.

In a small way, the quarries in the district here described have been worked for about a century. As early as 1850 Chapmans quarry, probably the oldest in the hard belt or area in which harder slate is mined, was in operation; the present company was organized in 1864 and had then a fair-sized opening on its property. About 1850, too, Robert M. Jones, the founder of Bangor, whose statue is to be seen on the campus of the Bangor High School, discovered slate east of the city, on the hill on which the masts of the Old Bangor quarry now stand. At an even earlier date, in the years between 1833 and 1841, H. D. Rogers, then State Geologist, and his associates found five quarries in operation at Slatington.[132] They also reported[133] two quarries working near the Delaware Water Gap, one of which was apparently the Old Jersey quarry of today, on the east bank of the Delaware River; the other would seem to have been what is now known as Williams quarry (see this report) in the Slateford group and was said to have begun work in 1812, though this is probably incorrect. In the same report mention is made of an opening, apparently Daniels quarry, one and one-half miles west of Nazareth.

In its growth the district has experienced the same depressions and revivals that have affected the industry throughout the nation. Quarries were first opened at Chapman and at various points in the hard belt, and the industry later received new recruits to its ranks from Bangor, Delpsburg (now East Bangor), Pen Argyl, and Hellerville (now a part of Wind Gap). As the industry enlarged it began to play a more important part in drawing workmen to the larger slate centers and Bangor, Pen Argyl, Wind Gap, Bath and Slateford became thriving small residential towns.

PRODUCTION

General discussion.—All varieties of slate products except slate pencils are obtained from the district here described. These include roofing slate, slate for structural and sanitary purposes (e. g., for sinks, mantels, drip-boards, shower stalls, and the like), grave vaults and covers, billiard table tops, electrical insulation and switch-board material

[132] Rogers, H. D.: Geology of Pennsylvania, vol. I, p. 249, 1858.
[133] Op. cit., p. 248.

(classed as "electrical slate"), blackboards and bulletin boards (lumped together under the trade term of blackboards), school slates, marbleized slate, crushed slate, and ground slate. The quarries of the soft belt yield all of these products; those of the hard belt furnish today only roofing slate and slate for such structural and sanitary uses as will require no finishing, although finished structural slate and even blackboards were once prepared with the aid of diamond saws at Chapman quarry in the hard belt. A large proportion of the slate production of the soft belt, and almost all of that of the hard belt is in the form of roofing slate.

The statistics and curves given below are obtained from figures in Mineral Resources of the United States* for the current years. The term "millstock" is loosely used. Millstock includes grave vaults, billiard table tops, structural and sanitary material, and electrical slate in the general curve for the United States as a whole (Figure 45). In the curve (Figure 46) comparing millstock production of the United

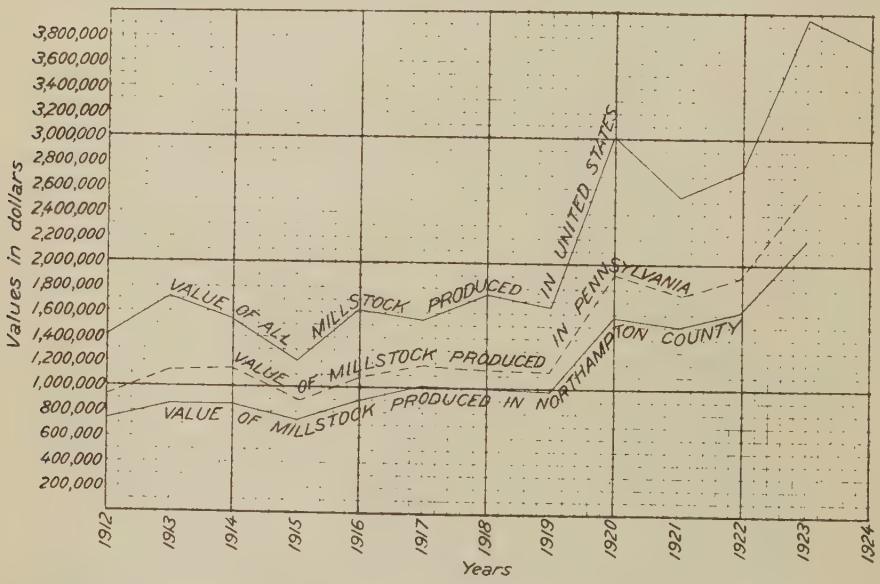


Figure 46. Relative values of millstock produced in the United States, Pennsylvania, and Northampton County, since 1912.

States with that of Pennsylvania and of Northampton County, however, the term millstock includes grave vaults, structural and sanitary material, blackboards, school slates and electrical slate, but does not include billiard table tops.

The figures represent the quantity or values sold, and so do not give the actual production, which may be more or less, according to whether

* Mineral Resources of the United States, U. S. Geol. Survey, Washington.

the producer is overstocked at the end of the year or drew on the supplies of the preceding year for his sales. The values quoted are f. o. b. at the point of shipment.

In the beginning, the quarries in the district, both in the hard and soft belts, yielded almost wholly roofing slate, and even today this makes up the greater part of the value of the production. Gradually, however, with increased use of structural slate, millstock rose to an important place. In these early days, as subsequently, development of the industry approximated on a smaller scale the progress of slate making in the nation as a whole. It was not long before Pennsylvania and more specifically Northampton County became the leading section of slate production in the nation. This position has been steadily held throughout the current century.

TABLE I.

Value of all slate sold in the United States and in Northampton County, 1913-1924.

Year	United States	Northampton County, Pa.
1913	$6,175,476	$2,897,205
1914	5,706,787	2,803,912
1915	4,958,915	2,438,933
1916	5,338,837	2,574,410
1917	5,749,966	2,813,902
1918	4,841,120	2,039,599
1919	6,030,648	2,578,025
1920	8,726,442	3,310,975
1921	7,322,006	3,062,389
1922	9,176,784	3,701,640
1923	12,076,624	4,557,809
1924	11,776,016	4,088,768

Figure 47 illustrates the relative importance of Northampton County in the slate production of the United States.

Figure 47. Relative values of slate production of the entire United States and Northampton County, 1913-1922, inclusive.

Before, however, discussing the production of slate in Northampton County, attention should be called to the sharp rise in the value and quantity of roofing slate produced in the years between 1890 and 1895 and the equally sharp decline in the ensuing five years. This sudden break was followed by a rapid rise, culminating in the peak production of 1903. To all appearances the production of roofing slate will continue to decline, because of the competition suffered from composition roofing, as mentioned above. The decline of roofing slate production, however, is being more than counterbalanced, it would appear from this curve, by the rise in sales of millstock.

Roofing slate.—Northampton County annually produces about two-fifths of all the roofing slate of the United States. Its total production for eleven years, beginning with 1912, represents over 46 per cent of that produced by the nation in the same period. It is here that the hard belt quarries contribute especially heavily, their other products being mainly a little rough structural material, such as grave vaults, flagging, and wall slate.

TABLE 2.

Value[1] of roofing slate produced in the United States and in Northampton County, 1912-1924.

Year	United States	Northampton County, Pa.
1912	$4,636,185	$1,857,255
1913	4,461,062	2,035,796
1914	4,160,832	1,942,555
1915	3,746,334	1,695,589
1916	3,408,934	1,667,738
1917	3,411,740	1,829,956[2]
1918	2,219,131	1,042,719
1919	3,085,957	1,543,750
1920	3,524,658	1,601,030
1921	3,197,745	1,407,283
1922	4,069,761	1,888,163
1923	4,582,535	2,201,515
1924	4,626,614	1,801,998

Millstock.—Next to roofing slate and gradually creeping up on it in value appears millstock. This increased importance of millstock is graphically demonstrated in Figure 46. It will be seen from the curve

[1] Values are f. o. b. at point of shipment.

[2] Includes the value produced by one quarry in York County, Pa.

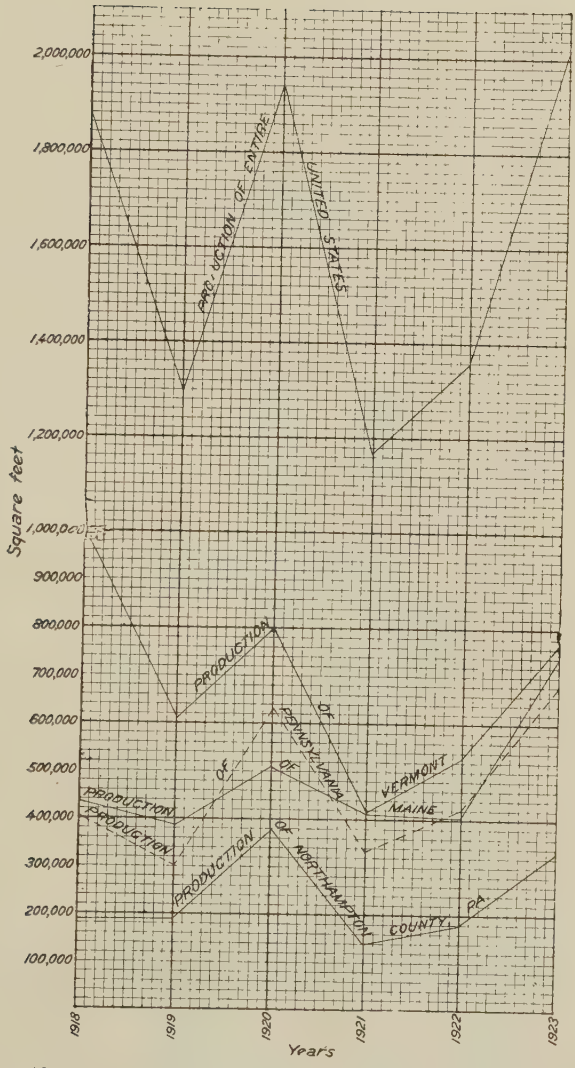


Figure 48. Production of electrical slate, 1918-1923, inclusive.

that since 1912 Pennsylvania has generally produced two-thirds of all the millstock of the United States. If billiard table tops were included in these figures the proportion would be better than two-thirds of the total national production in every year since 1912. Of the two-thirds, Northampton County has generally produced between three-fourths and four-fifths, in later years even more.

Electrical slate.—Two special slate products sometimes classed under millstock have become of major importance in recent years (Figure 48). Of these one is electrical slate, which has only attained prominence since about 1918. Here Vermont is the main producer, and Pennsylvania, with Northampton County yielding about half its supply, shares second place with Maine.

Blackboard slate.—The production of slate blackboards and bulletin boards is confined almost wholly to Pennsylvania. Of this, Northampton County has generally furnished the larger share, especially so since 1920 (Figure 49). The wide beds between the "ribbons" of

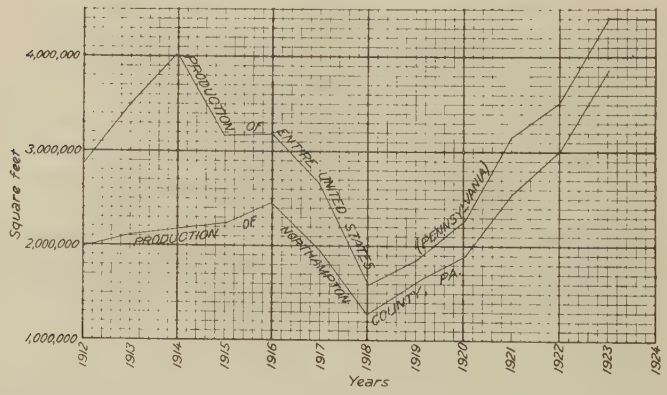


Figure 49. Production of blackboard slate, 1912-1923, inclusive.

the soft belt, particularly those at Pen Argyl, are especially favorable for blackboard material. It has been hoped, also, that some faintly ribboned slate might come to be used where specifications would permit it.

School slate.—On the other hand, Lehigh County, with Slatington as its main center, generally doubles the output of its sister county in school slates, as may be seen in the following table. There was in 1923 only one small school slate factory in Northampton County.

TABLE 3.

Value of school slates produced in Lehigh and in Northampton counties, Pennsylvania, 1913-1922.

Year	Lehigh County	Northampton County
1913	$34,329	$16,984
1914	26,897	8,308
1915	25,861	12,306
1916	33,495	19,066
1917	28,012	20,816
1918	6,953	10,063
1919	31,992	22,643
1920	62,749	20,240
1921	42,591	13,579
1922	30,105	11,922
	$322,984	$155,927

The persistence of the school slate market (largely European) in the last ten years is an answer to the fears expressed by many slate men that the demand for this product will suffer further decline.

Minor products.—Of lesser products there are several that deserve mention. In the section of Northampton County here considered, one company is manufacturing marbleized slate. Two grinding plants for making powdered slate and granules have been established, one at Bangor and one at Pen Argyl; another was built in 1923 at Columbia, N. J., but contemplated using Vermont, rather than Pennsylvania, slate.

Remarks.—For the notable increase in slate production and consumption in the United States during recent years, credit should be given at least in part to the recent organizations of slate producers. There are at least three such organizations,—the Structural Slate Company, the Vendor Slate Company, and the Natural Slate Blackboard Company, which, with the National Slate Association, have helped standardize and advertise slate products. This work is of the highest value to producer and consumer alike.

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